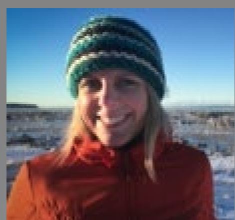
ACLIM
The Alaska Climate Integrated Modeling project



Kirstin Holsman Kirstin.Holsman@noaa.gov

Alan Haynie Alan.Haynie@noaa.gov

Kerim Aydin Kerim.Aydin@noaa.gov
NOAA Alaska Fisheries Science Center

Crab results from:

Cody Szuwalski

Buck Stockhausen

Anne Hollowed, NOAA

Al Hermann, UW

Jonathan Reum, NOAA

André Punt, UW

+ ACLIM Team

NPFMC Crab Plan Team – January 2022

ACLIM Team

Building climate resilience through climate-informed Ecosystem Based Management advice

Lead PIs: Anne Hollowed, Kirstin Holsman, Alan Haynie, Jon Reum, Andre Punt, Kerim Aydin, Al Hermann

Co-Pis & Collaborators

Wei Cheng
Jim Ianelli
Kelly Kearney
Elizabeth McHuron
Daren Pilcher
Jeremy Sterling
Ingrid Spies
Paul Spencer
William Stockhausen
Cody Szuwalski
Sarah Wise
Ellen Yasumiishi

Andy Whitehouse
James Thorson
Peggy Sullivan
Amanda Faig
Steve Kasperski
Martin Dorn
Diana Evans
Ed Farly
Enrique Curchitser
Elliott Hazen
David Kimmel
Mike Jacox
Adam Hayes

Carol Ladd
Stan Kotwicki
Ivonne Ortiz
Kalei Shotwell
Rolf Ream
Elizabeth Siddon
Phyllis Stabeno
Charlie Stock
Chris Rooper
Jordan Watson
Diana Stram
Lauren Rogers
Ben Laurel

www.fisheries.noaa.gov/alaska/ecosystems/alaska-climate-integrated-modeling-project

IPCC 6th Assessment Report (2021)

https://www.ipcc.ch/

Warming in the Arctic is 2-3 x global average

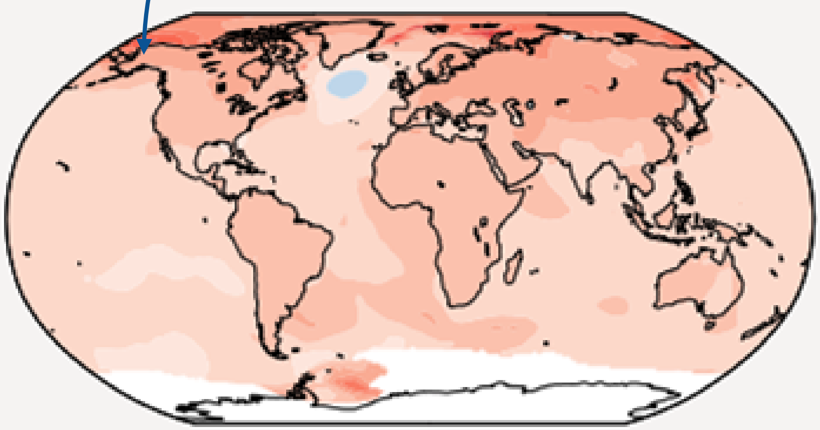
1.07^{o}C of "Global mean warming" = Warming of 2-3oC in the Arctic

"Polar Amplification"

a) Annual mean temperature change (°C) at 1 °C global warming

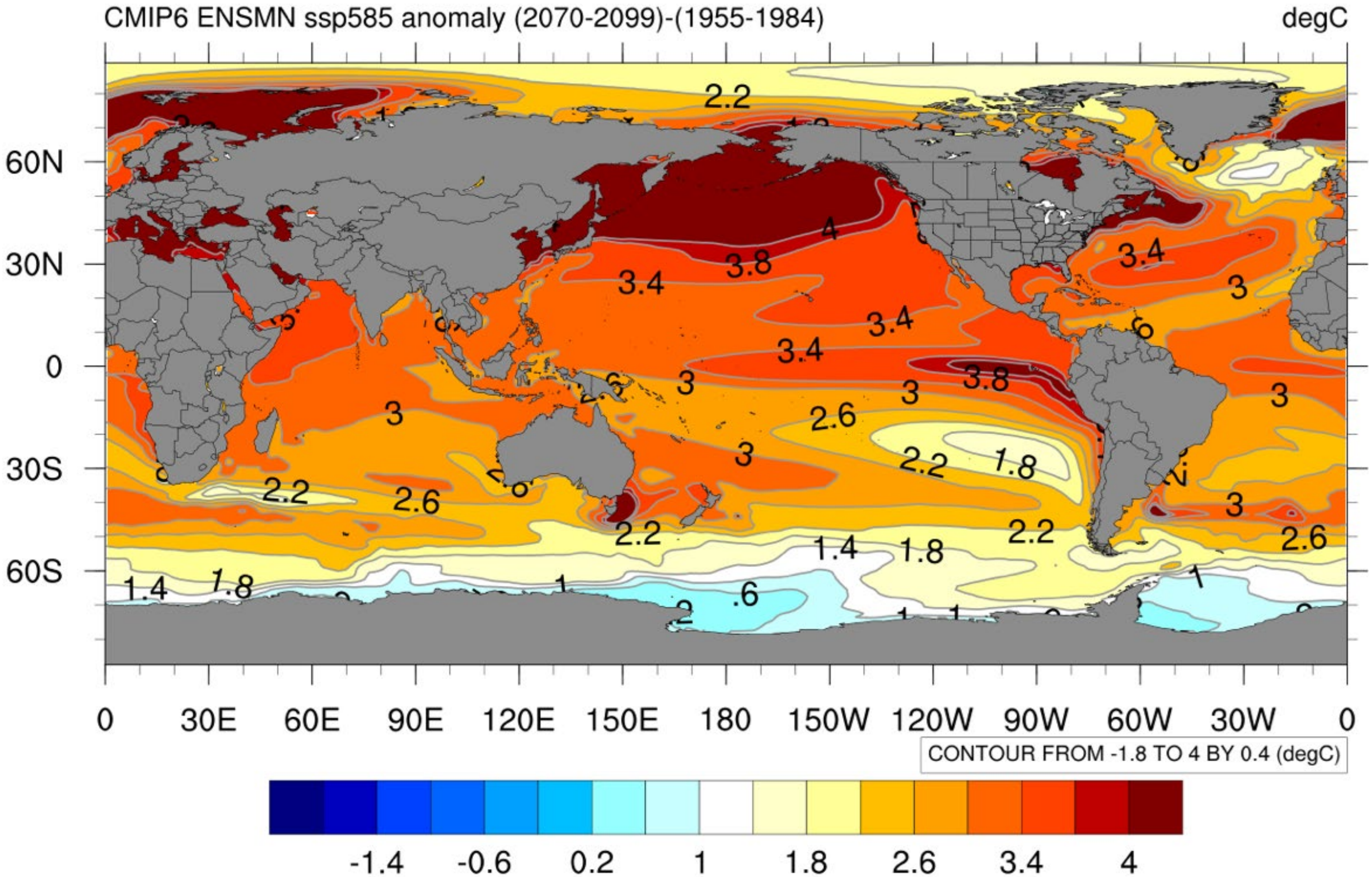
Warming at 1 °C affects all continents and is generally larger over land than over the oceans in both observations and models. Across most regions, observed and simulated patterns are consistent.

Observed change per **1 °C** global warming



Figures from the IPCC AR6 WGI Summary for Policymakers: https://www.ipcc.ch/report/ar6/wg1/downloads/report/IPCC_AR6_WGI_SPM.pdf

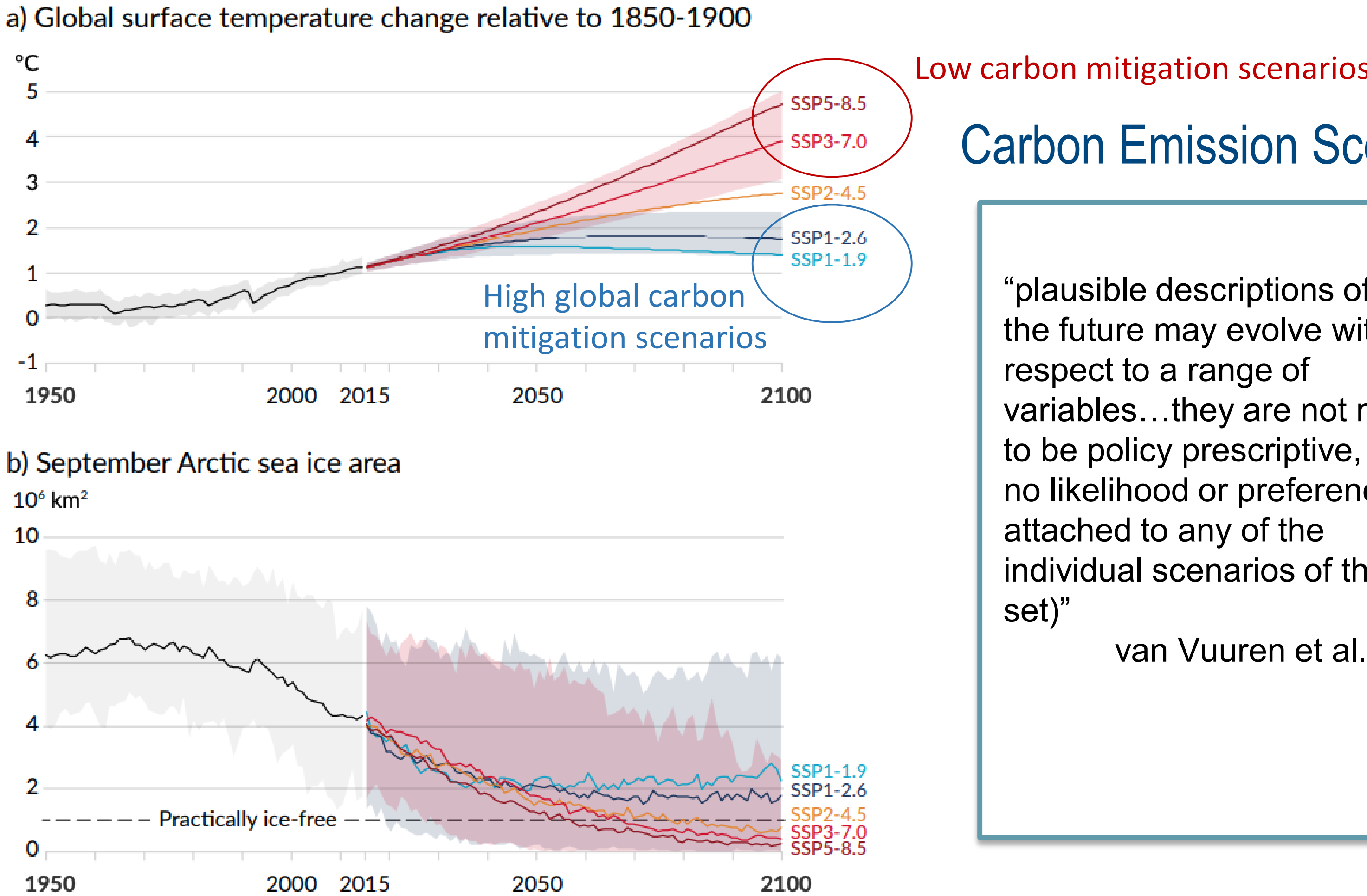
Climate change is expected to continue to impact AK Ecosystems & Fisheries



https://psl.noaa.gov/ipcc/cmip6/

Not just the averages: Increased intensity, frequency, duration of Marine Heat Waves

Climate change is expected to continue to impact AK Ecosystems & Fisheries



Carbon Emission Scenarios

"plausible descriptions of how the future may evolve with respect to a range of variables…they are not meant to be policy prescriptive, (i.e. no likelihood or preference is attached to any of the individual scenarios of the set)"

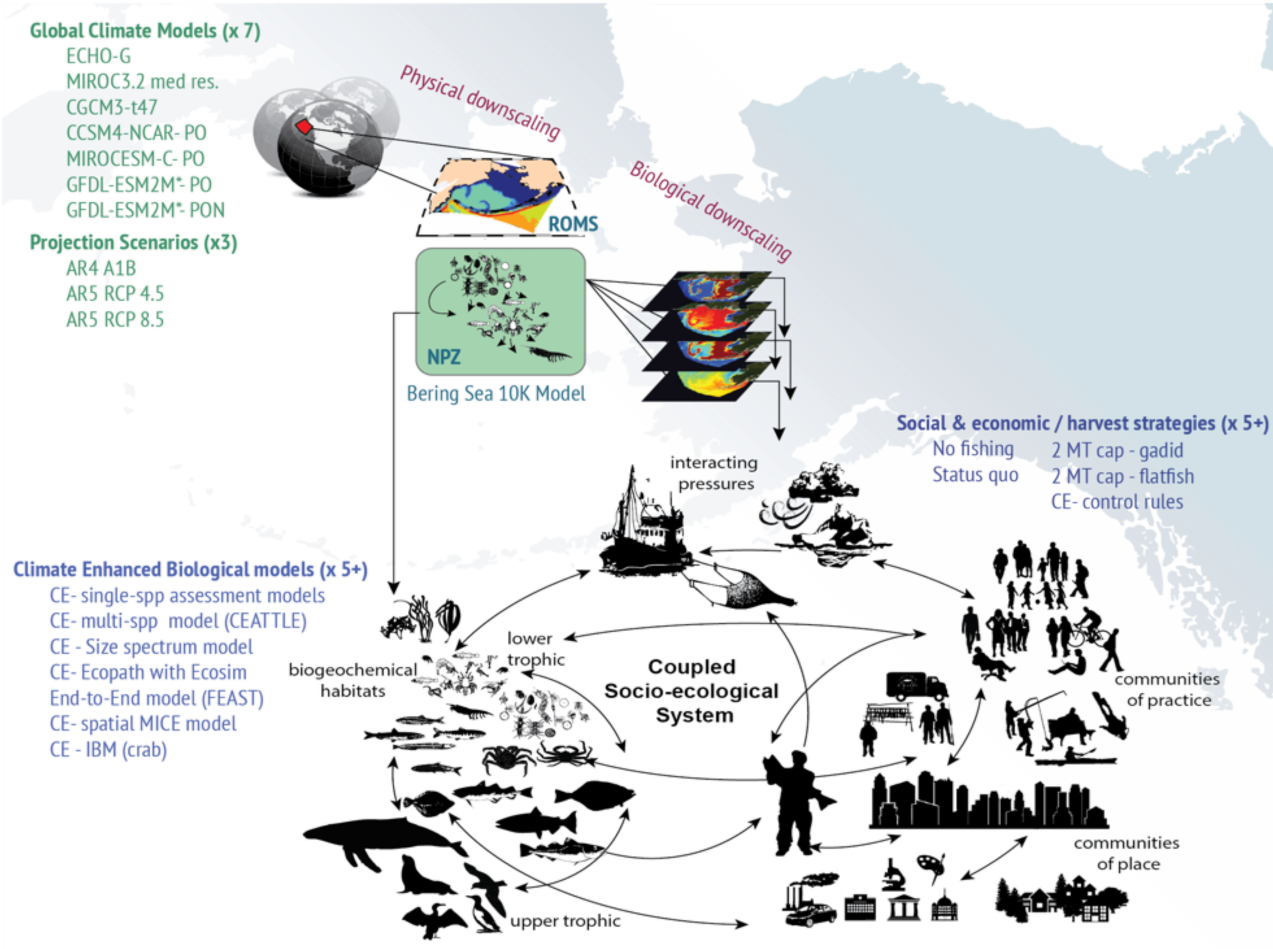
van Vuuren et al. 2011

Figures from the IPCC AR6 WGI Summary for Policymakers: https://www.ipcc.ch/report/ar6/wg1/downloads/report/IPCC_AR6_WGI_SPM.pdf

ACLIM The Alaska Climate Integrated Modeling Project NOAA Alaska Fisheries Science Center

The Alaska Climate Integrated Modeling Project (Bering Sea)

www.fisheries.noaa.gov/alaska/ecosystems/alaska-climate-integrated-modeling-project



Hollowed et al. 2020. Frontiers in Mar. Sci. doi: 10.3389/fmars.2019.00775

UNIVERSITY of WASHINGTON
School of Aquatic and Fishery Sciences
PMEL
JISAO
Joint Institute for the Study of the Atmosphere and Ocean
IEA INTEGRATED ECOSYSTEM ASSESSMENT
NOAA FISHERIES

ACLIM (Bering Sea) and GOACLIM (Gulf of Alaska) are individual fisheries management-oriented projects within Alaska Fisheries Science Center's broad Regional Action Plans for Climate, that include monitoring, modeling, and synthesis.

Summary of the existing climate-related research portfolio for the EBS (see Appendix 1 for detailed project descriptions).

Theme	**Total**	**Continuing**	**New**
Monitoring	12	10	2
Process Studies	8	6	2
Management Oriented Synthesis	18	4	14
Marine Mammals	1*	1	
Socioeconomics	12	7	5
Total	51	28	23

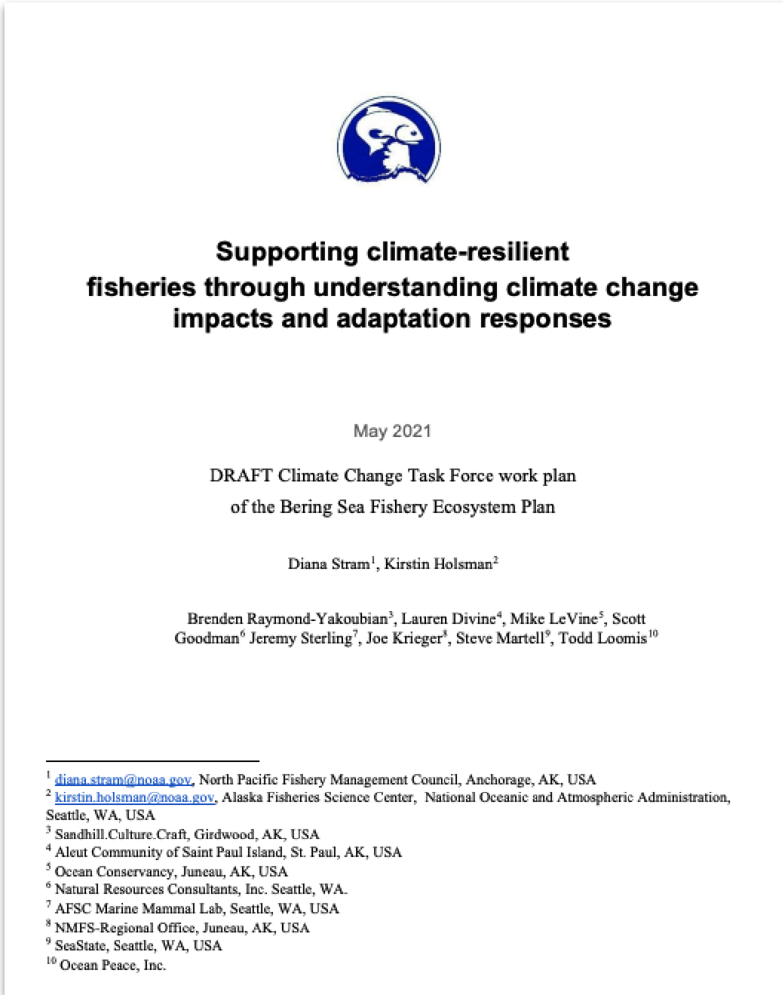
From Hollowed et al. Bering Sea Regional Action Plan draft presented to North Pacific Fishery Management Council (October 2021)

SCIENCE
ACLIM (Bering Sea) and GOACLIM (Gulf of Alaska) are individual fisheries management-oriented projects within Alaska Fisheries Science Center's broad Regional Action Plans for Climate, that include monitoring, modeling, and synthesis.

MANAGEMENT
The NPFMC Fisheries Ecosystem Plan Team for the Bering Sea, and the FEP's Climate Change Task Force develop stakeholder-oriented onramps for bringing climate advice into active fisheries management.

contacts: *Diana Stram, Diana Evans (Council)*
Kirstin Holsman, Kerim Aydin (AFSC)

Provide tools and approaches to support climate informed management decisions



Supporting climate-resilient fisheries through understanding climate change impacts and adaptation responses

May 2021

DRAFT Climate Change Task Force work plan
of the Bering Sea Fishery Ecosystem Plan

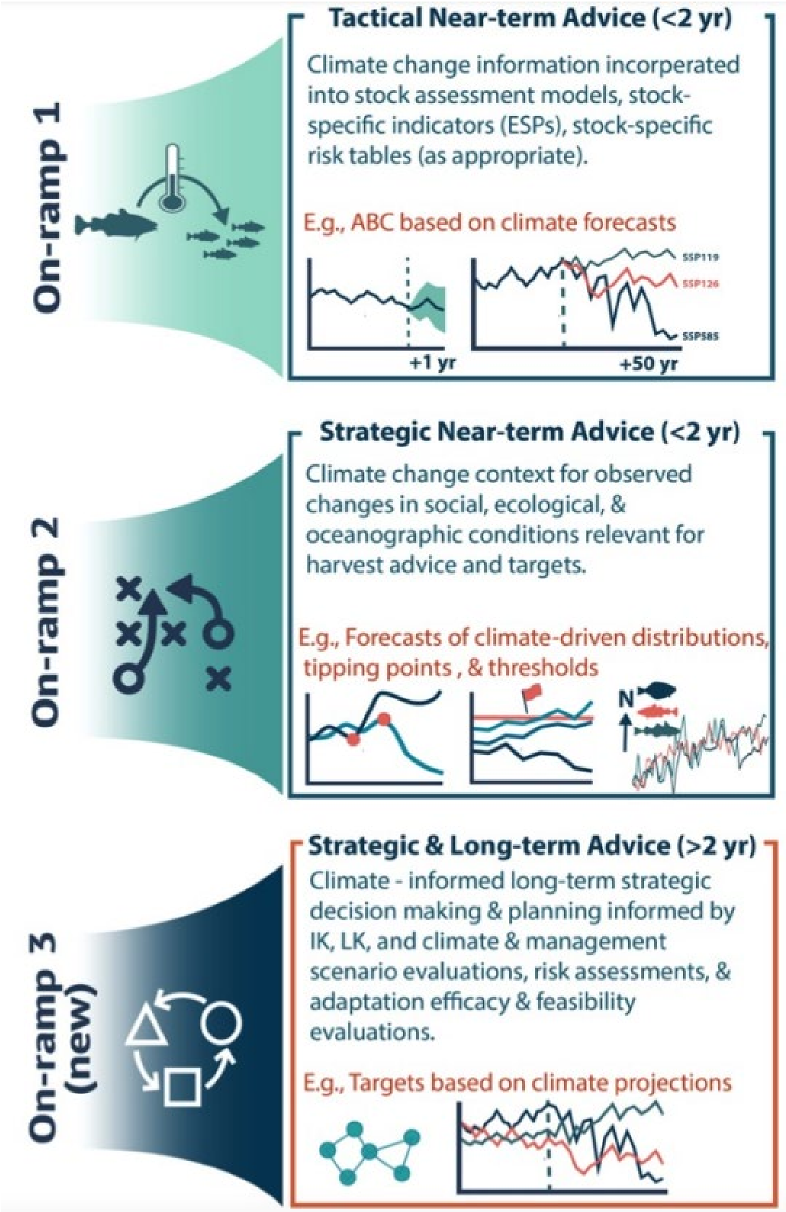
Diana Stram[1], Kirstin Holsman[2]

Brenden Raymond-Yakoubian[3], Lauren Divine[4], Mike LeVine[5], Scott Goodman[6] Jeremy Sterling[7], Joe Krieger[8], Steve Martell[9], Todd Loomis[10]

[1] diana.stram@noaa.gov, North Pacific Fishery Management Council, Anchorage, AK, USA
[2] kirstin.holsman@noaa.gov, Alaska Fisheries Science Center, National Oceanic and Atmospheric Administration, Seattle, WA, USA
[3] Sandhill.Culture.Craft, Girdwood, AK, USA
[4] Aleut Community of Saint Paul Island, St. Paul, AK, USA
[5] Ocean Conservancy, Juneau, AK, USA
[6] Natural Resources Consultants, Inc. Seattle, WA.
[7] AFSC Marine Mammal Lab, Seattle, WA, USA
[8] NMFS-Regional Office, Juneau, AK, USA
[9] SeaState, Seattle, WA, USA
[10] Ocean Peace, Inc.

https://www.npfmc.org/climatechangetaskforce/
Stram et al. 2021

Climate information on ramps for fisheries management



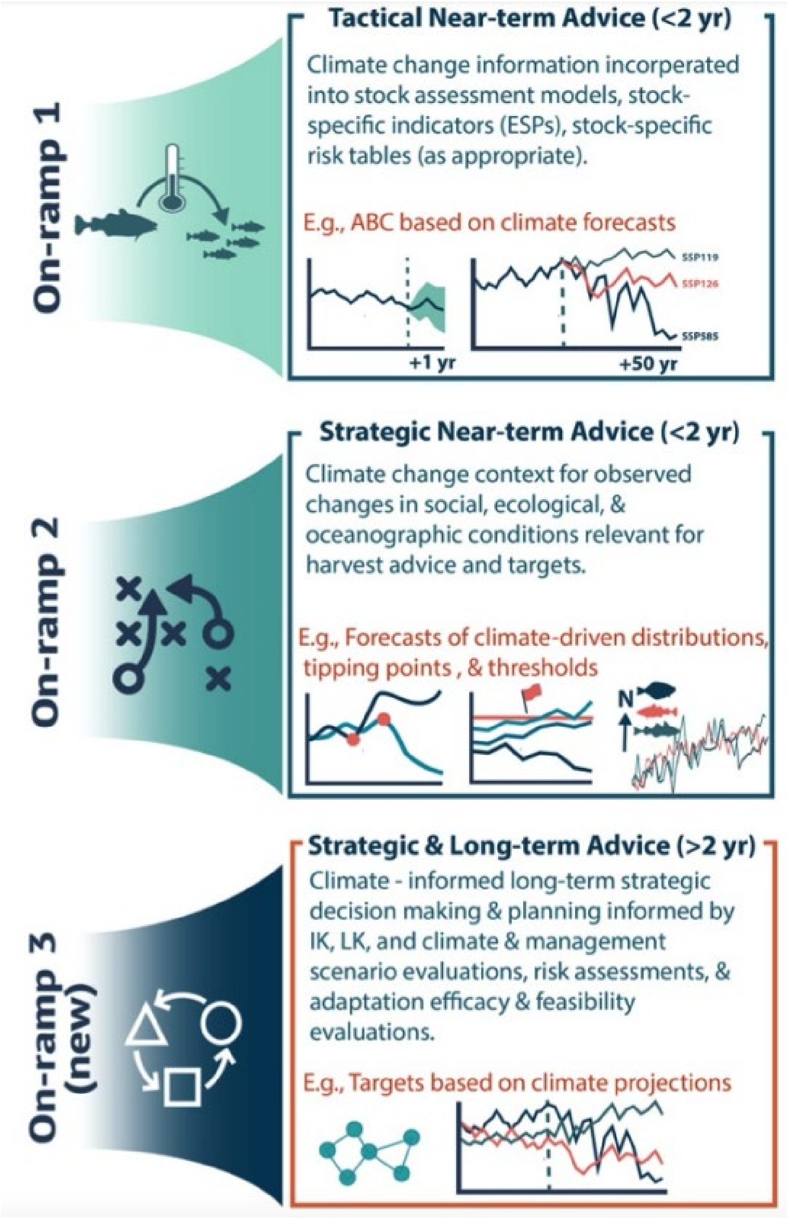
Provide tools and approaches to support climate informed management decisions

Climate informed annual* stock assessments & advice

Climate information in near-term management targets

Climate information in long-term management targets and design

Climate information on ramps for fisheries management



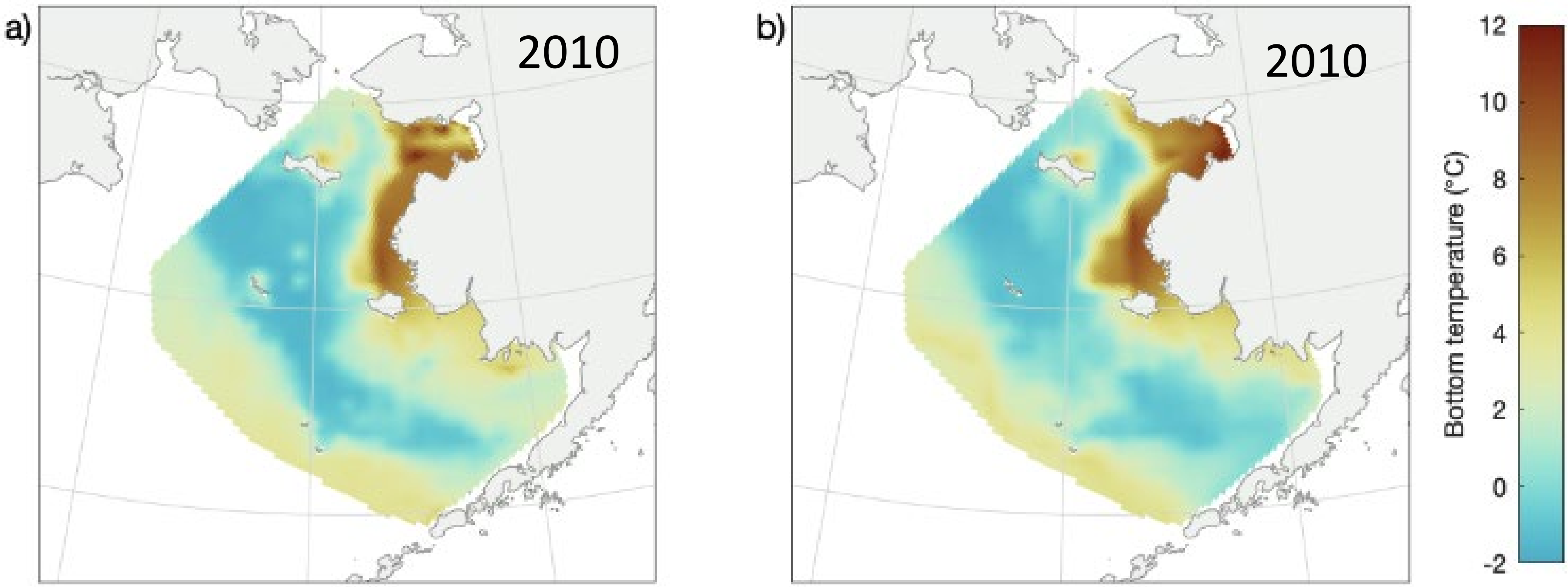
https://www.npfmc.org/climatechangetaskforce/

Bering Sea Oceanographic Projections

High-res model reproduces the Bering Sea environment

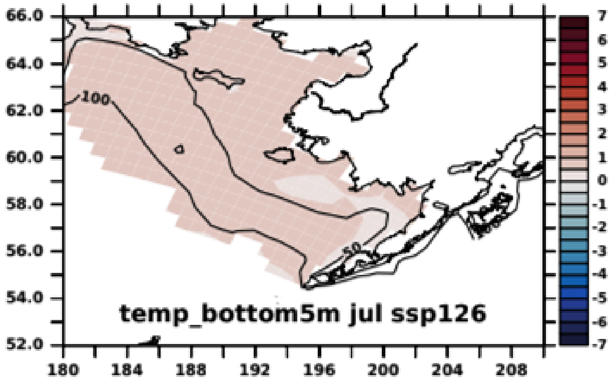
Observed (survey data)

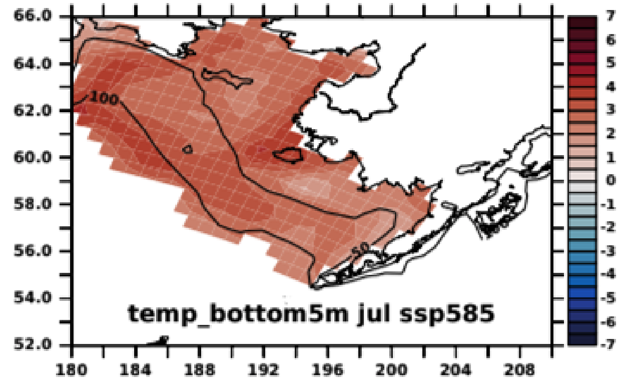
Model (Bering10K ROMSNPZ)



Kearney K (2021). Temperature data from the eastern Bering Sea continental shelf bottom trawl survey as used for hydrodynamic model validation and comparison. U.S. Dep. Commer., NOAA Tech. Memo. NMFS-AFSC-415, 40 p. link.

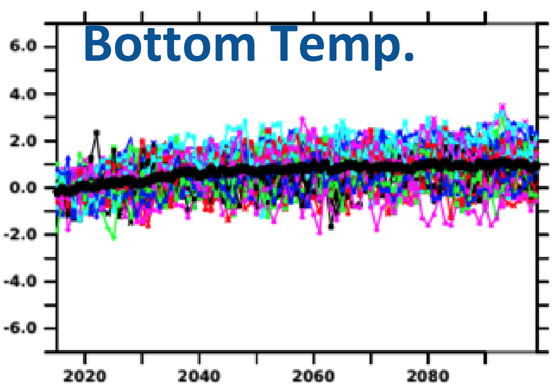
Increased warming expected

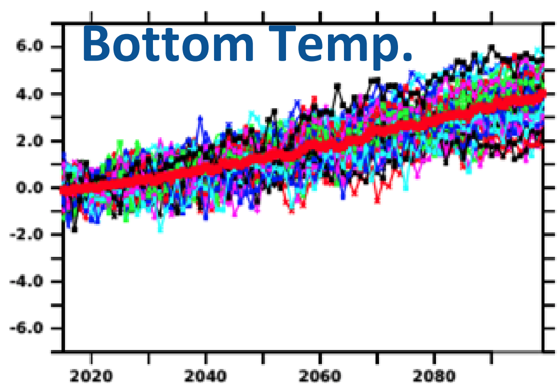




SSP126: High mitigation/ less warming

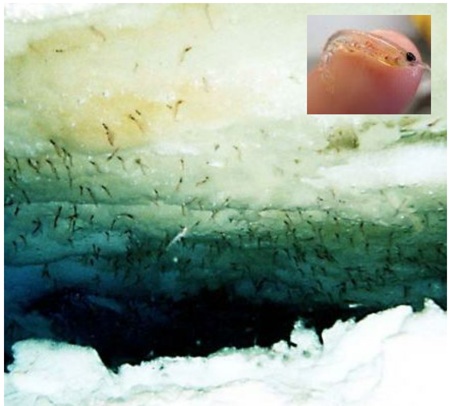
SSP585: Low mitigation/ more warming

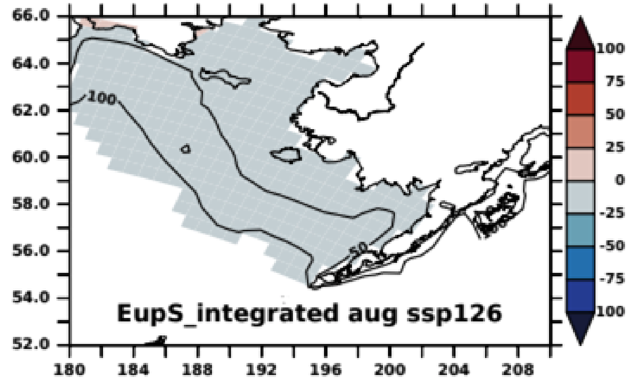


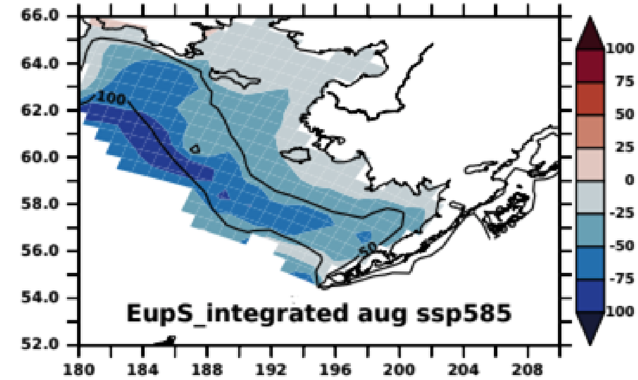


Hermann et al. https://doi.org/10.1016/j.dsr2.2021.104974

Declines in Euphausiids (krill) expected



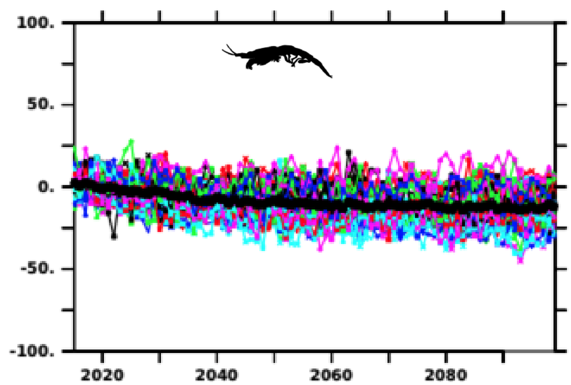


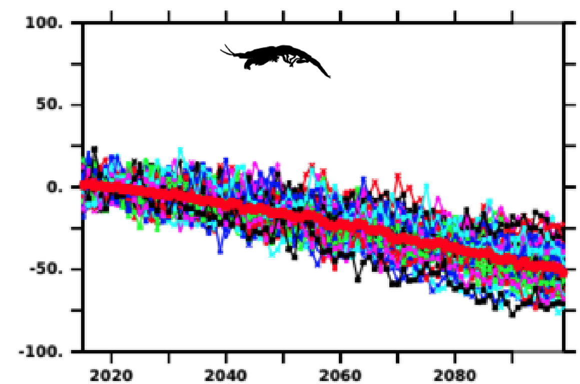


Euphausiid biomass

SSP126: High mitigation/ less warming

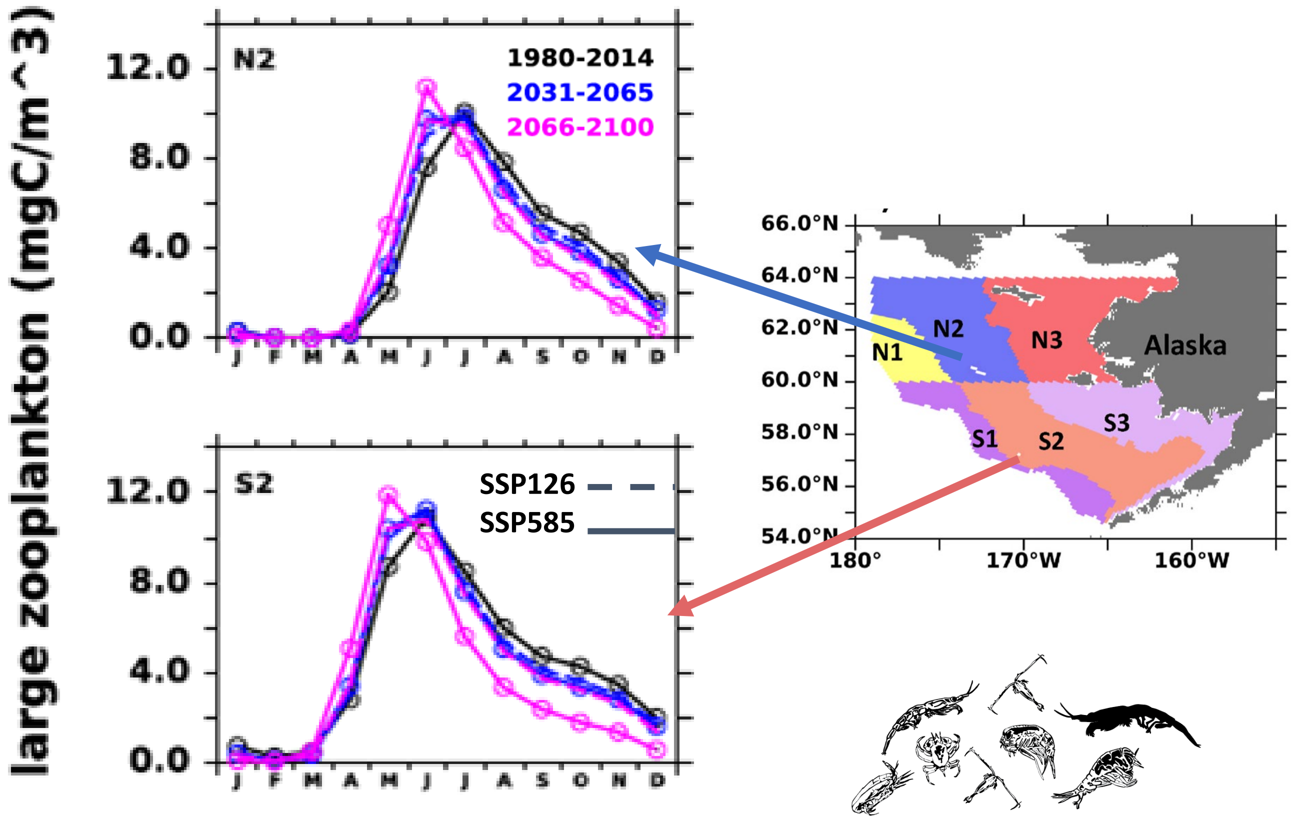
SSP585: Low mitigation/ more warming





Hermann et al. https://doi.org/10.1016/j.dsr2.2021.104974

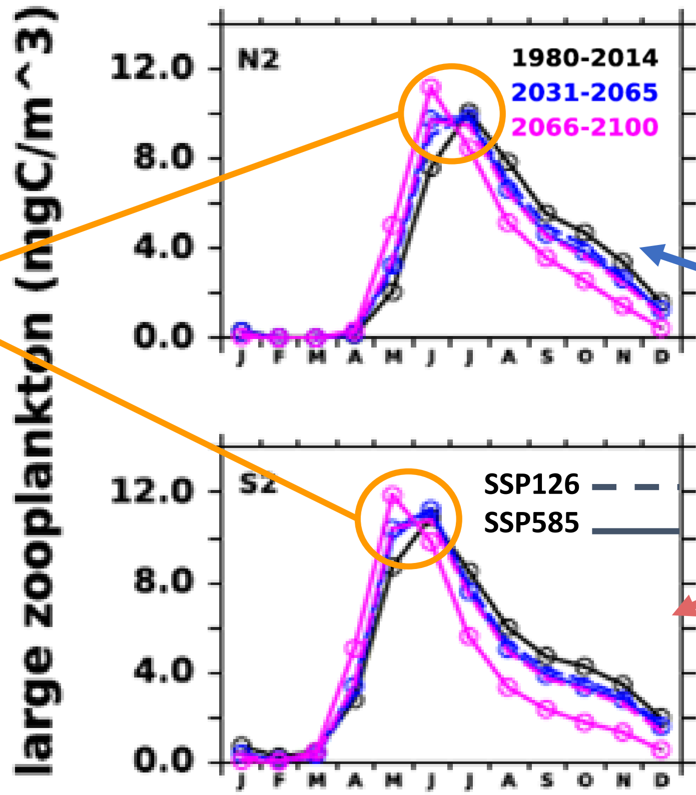
Change in the timing (phenology) of prey resources

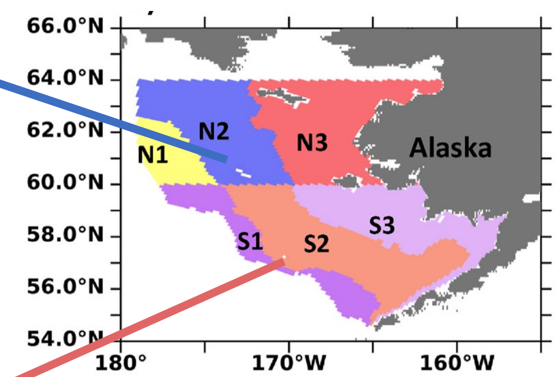


Cheng, et al. (2021) https://www.sciencedirect.com/science/article/pii/S0967064521000515

Change in the timing (phenology) of prey resources

Shift earlier in zooplankton peak under low mitigation (high warming) scenarios





Cheng, et al. (2021) https://www.sciencedirect.com/science/article/pii/S0967064521000515

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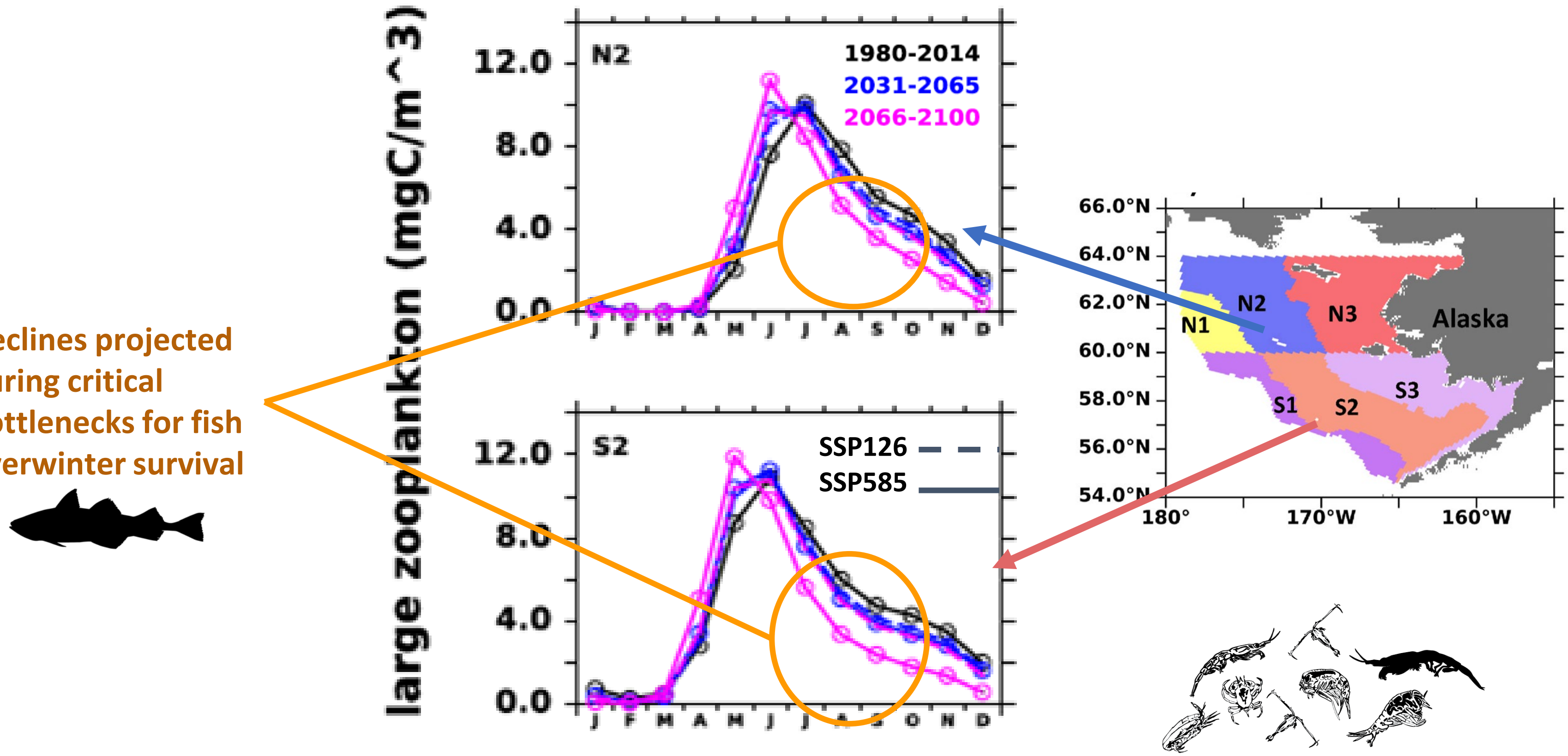
NOAA Alaska Fisheries Science Center

Change in the timing (phenology) of prey resources



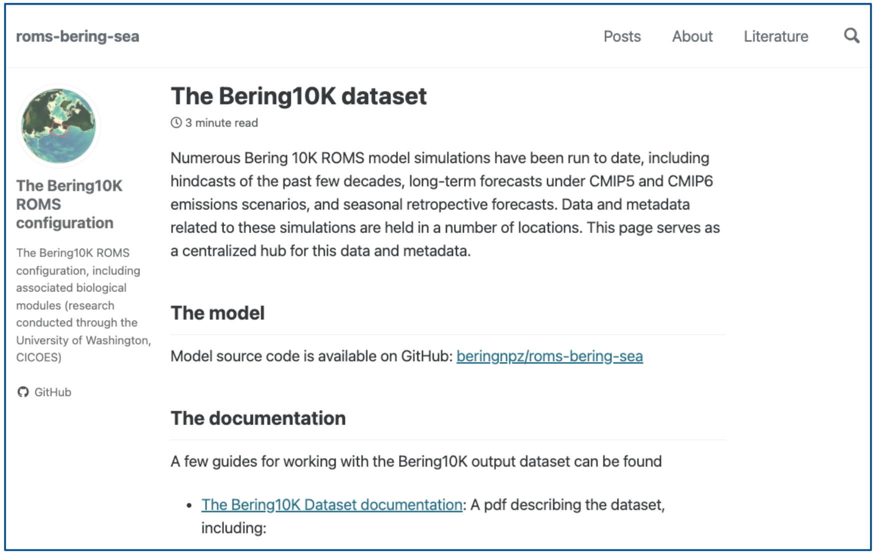
Declines projected during critical bottlenecks for fish overwinter survival

Cheng, et al. (2021) https://www.sciencedirect.com/science/article/pii/S0967064521000515

Learn More: BERING10K Data & Info portals

Learn More:
https://beringnpz.github.io/roms-bering-sea/B10K-dataset-docs/

Explore the Data:
https://github.com/kholsman/ACLIM2


roms-bering-sea   Posts   About   Literature

The Bering10K ROMS configuration

The Bering10K ROMS configuration, including associated biological modules (research conducted through the University of Washington, CICOES)

GitHub

The Bering10K dataset

3 minute read

Numerous Bering 10K ROMS model simulations have been run to date, including hindcasts of the past few decades, long-term forecasts under CMIP5 and CMIP6 emissions scenarios, and seasonal retropective forecasts. Data and metadata related to these simulations are held in a number of locations. This page serves as a centralized hub for this data and metadata.

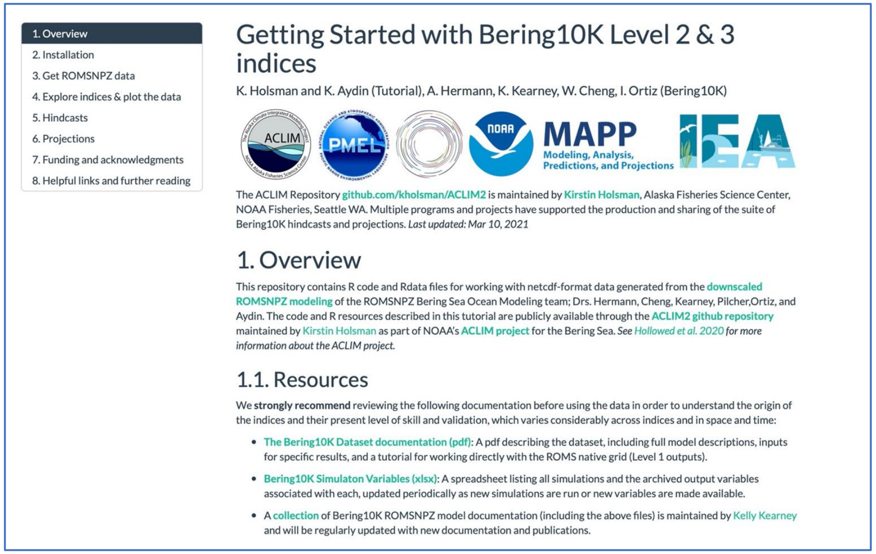
The model

Model source code is available on GitHub: beringnpz/roms-bering-sea

The documentation

A few guides for working with the Bering10K output dataset can be found

- The Bering10K Dataset documentation: A pdf describing the dataset, including:


1. Overview
2. Installation
3. Get ROMSNPZ data
4. Explore indices & plot the data
5. Hindcasts
6. Projections
7. Funding and acknowledgments
8. Helpful links and further reading

Getting Started with Bering10K Level 2 & 3 indices

K. Holsman and K. Aydin (Tutorial), A. Hermann, K. Kearney, W. Cheng, I. Ortiz (Bering10K)

The ACLIM Repository github.com/kholsman/ACLIM2 is maintained by Kirstin Holsman, Alaska Fisheries Science Center, NOAA Fisheries, Seattle WA. Multiple programs and projects have supported the production and sharing of the suite of Bering10K hindcasts and projections. *Last updated: Mar 10, 2021*

1. Overview

This repository contains R code and Rdata files for working with netcdf-format data generated from the downscaled ROMSNPZ modeling of the ROMSNPZ Bering Sea Ocean Modeling team; Drs. Hermann, Cheng, Kearney, Pilcher,Ortiz, and Aydin. The code and R resources described in this tutorial are publicly available through the ACLIM2 github repository maintained by Kirstin Holsman as part of NOAA's ACLIM project for the Bering Sea. *See Hollowed et al. 2020 for more information about the ACLIM project.*

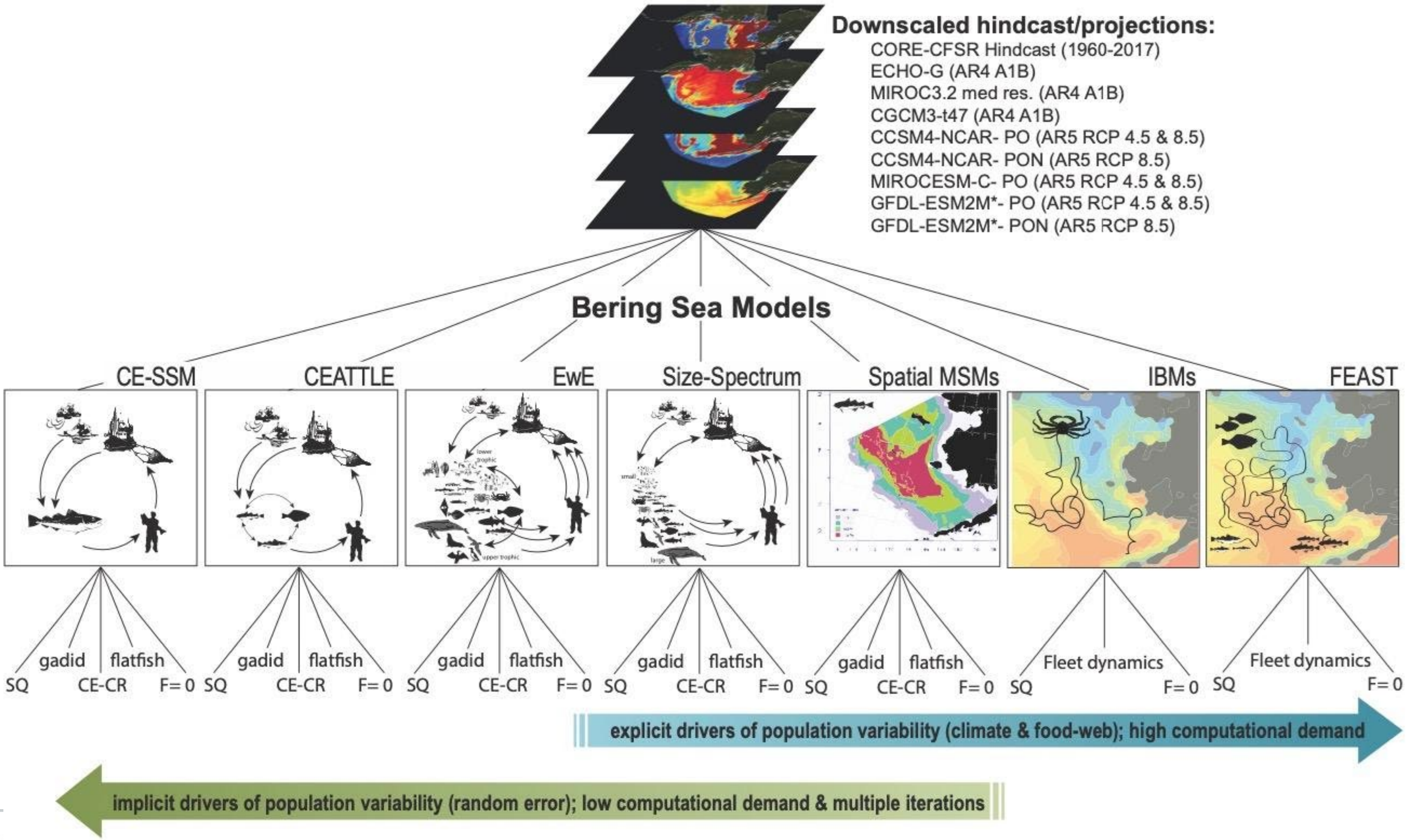
1.1. Resources

We **strongly recommend** reviewing the following documentation before using the data in order to understand the origin of the indices and their present level of skill and validation, which varies considerably across indices and in space and time:

- The Bering10K Dataset documentation (pdf): A pdf describing the dataset, including full model descriptions, inputs for specific results, and a tutorial for working directly with the ROMS native grid (Level 1 outputs).
- Bering10K Simulaton Variables (xlsx): A spreadsheet listing all simulations and the archived output variables associated with each, updated periodically as new simulations are run or new variables are made available.
- A collection of Bering10K ROMSNPZ model documentation (including the above files) is maintained by Kelly Kearney and will be regularly updated with new documentation and publications.

Climate + Biological + Management Modeling

The Alaska Climate Integrated Modeling Project



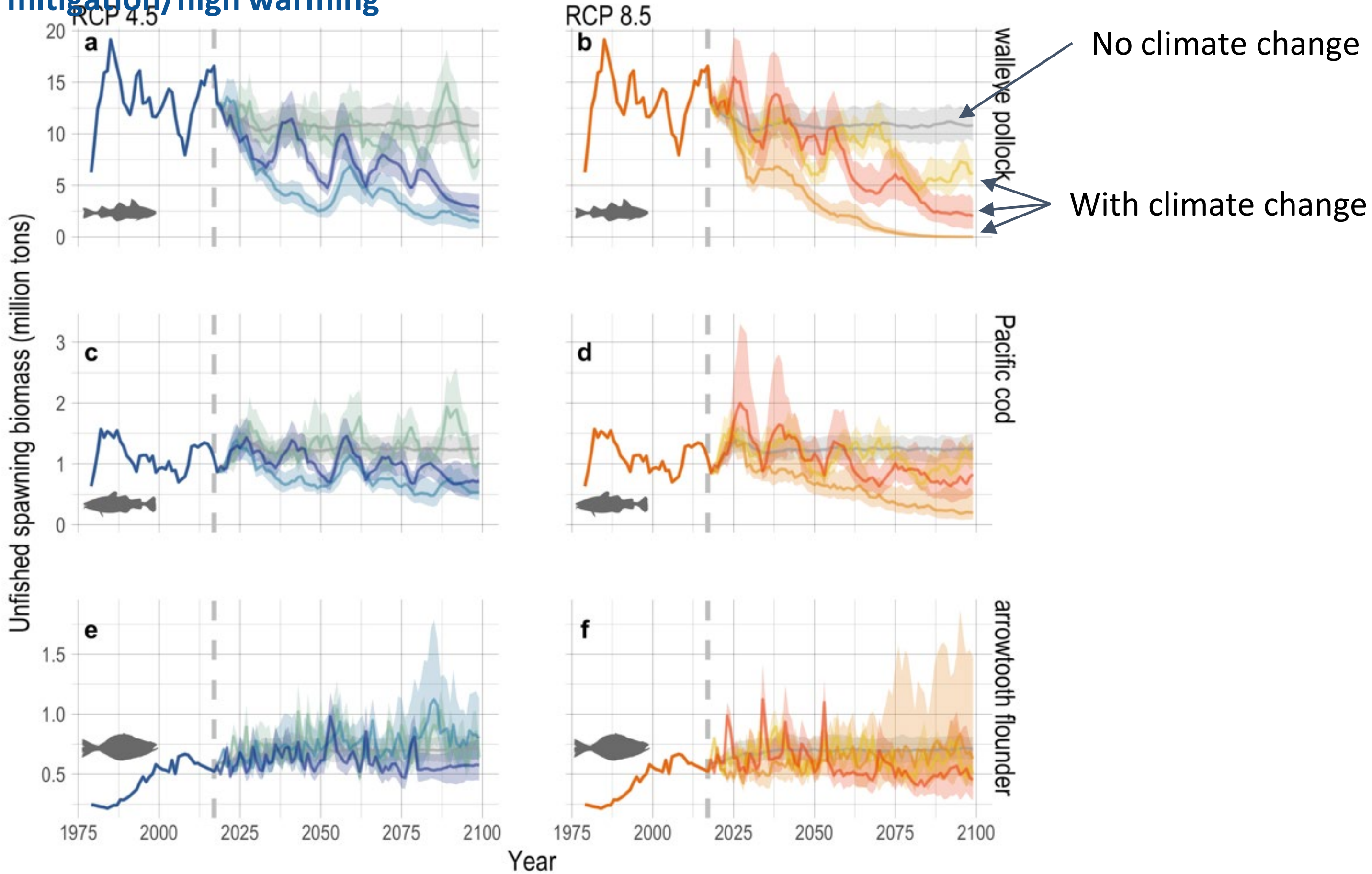
CEATTLE: Unfished biomass (no harvest)

Assumes climate effects on recruitment, growth, & mortality

More warming =

- larger declines
- higher agreement of declines

moderate mitigation/warming **low mitigation/high warming**



Holsman, K.K., Haynie, A.C., Hollowed, A.B. et al. Ecosystem-based fisheries management forestalls climate-driven collapse. Nat Commun 11, 4579 (2020). https://doi.org/10.1038/s41467-020-18300-3

Rpath() / EwE (Whitehouse et al. 2021)

Assumes food web dynamics are a function of biomass

General declines in seabirds

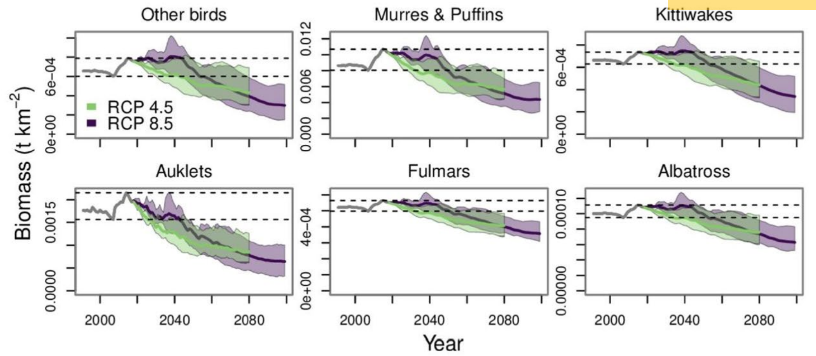


FIGURE 8 | Biomass projections for seabird functional groups. The gray line from 1991 to 2017 indicates the historical period. The purple and green poly indicate the minimum and maximum range for the three earth system models run under each RCP. The purple and green lines indicate the mean of the th each RCP. The dashed lines indicate the minimum and maximum values from the historical period.

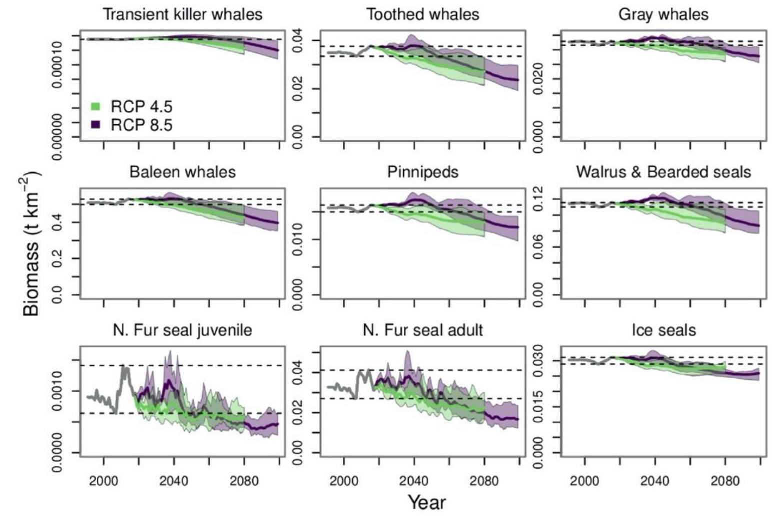


FIGURE 7 | Biomass projections for marine mammal functional groups. The gray line from 1991 to 2017 indicates the historical period. The purple and green polygons indicate the minimum and maximum range for the three earth system models run under each RCP. The purple and green lines indicate the mean of the three runs for each RCP. The dashed lines indicate the minimum and maximum values from the historical period.

General declines in marine mammals

Whitehouse, et al. 2021. Bottom-up impacts of forecasted climate change on the eastern Bering Sea food web. Front. Mar. Sci., 03 February 2021 | https://doi.org/10.3389/fmars.2021.624301

ICES Journal of Marine Science

Climate change and the future productivity and distribution of crab in the Bering Sea

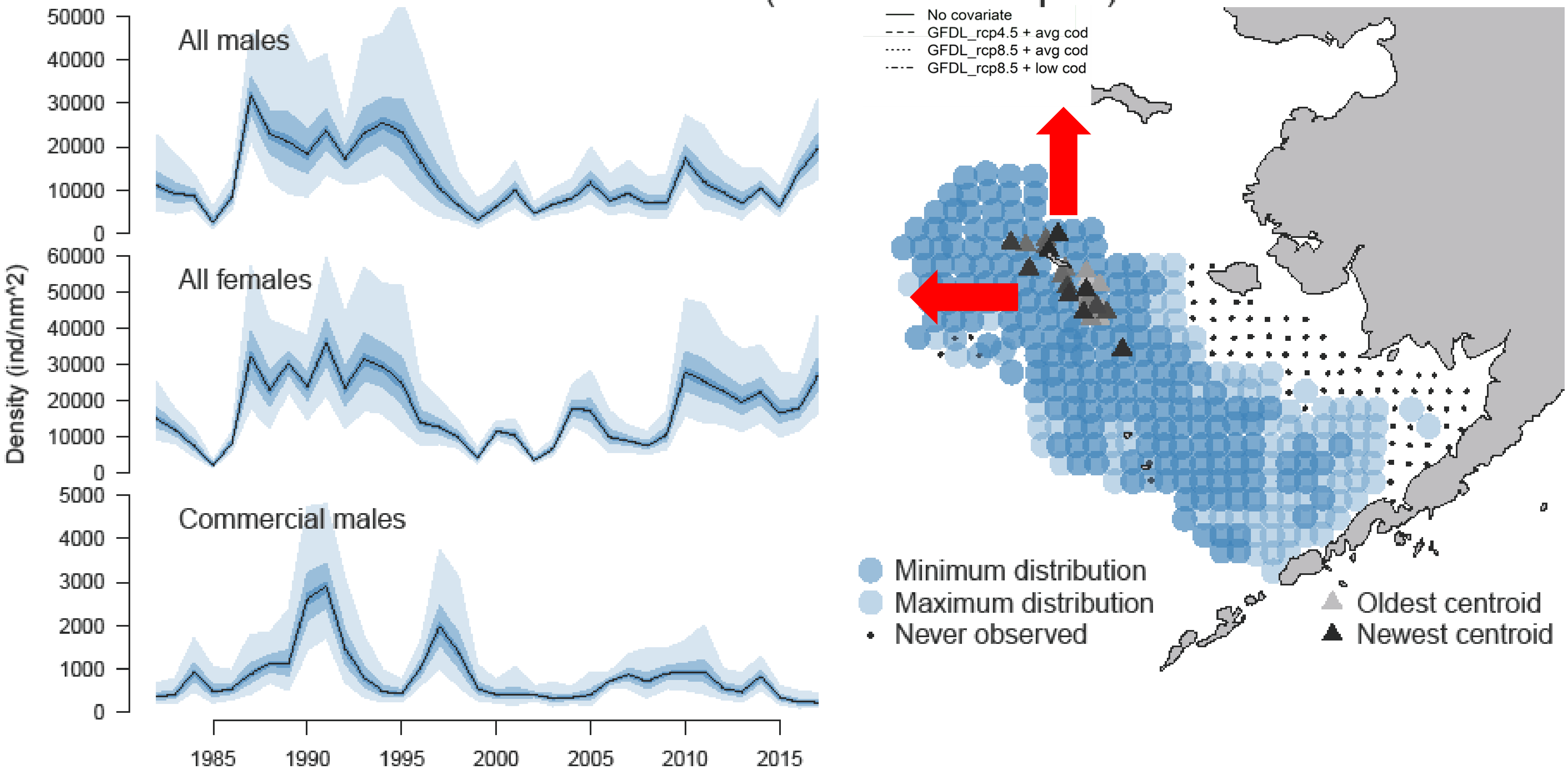
Cody Szuwalski [1*], Wei Cheng [2,3], Robert Foy [4], Albert J. Hermann [2,3], Anne Hollowed [1], Kirstin Holsman [1], Jiwoo Lee [5], William Stockhausen [1], and Jie Zheng [6]

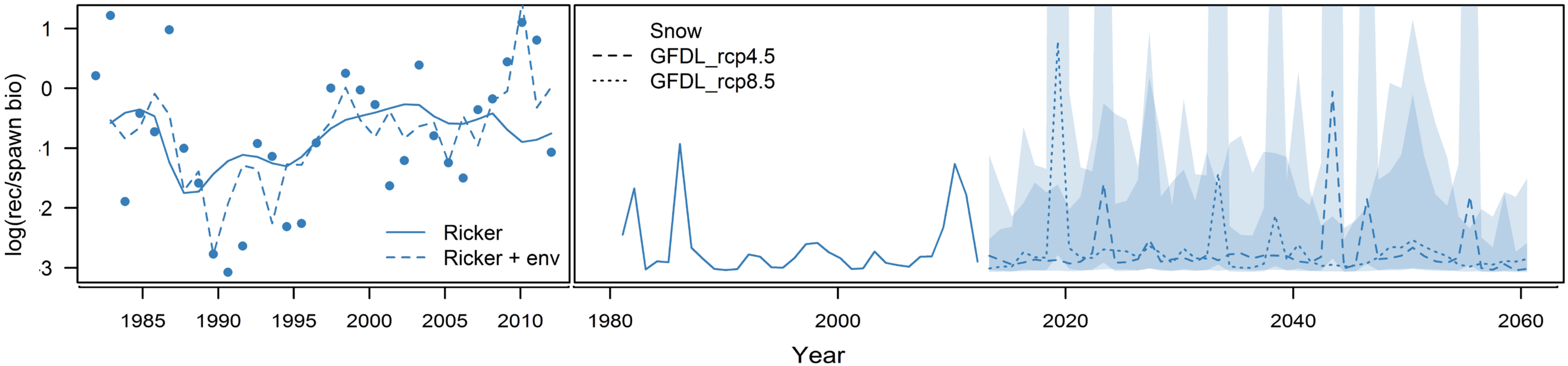
How have the distribution and productivity changed for the major crab stocks in the Bering Sea?

Can we explain any of these changes with environmental indices?

Can we project what might be expected of these stocks in the future given observed relationships?

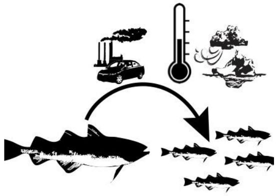
Snow crab (Chionoecetes opilio)





Less productive in the long term in the current area due to decreased ice cover and changes in arctic oscillation

ACLIM 1.0 Scenarios - groundfish

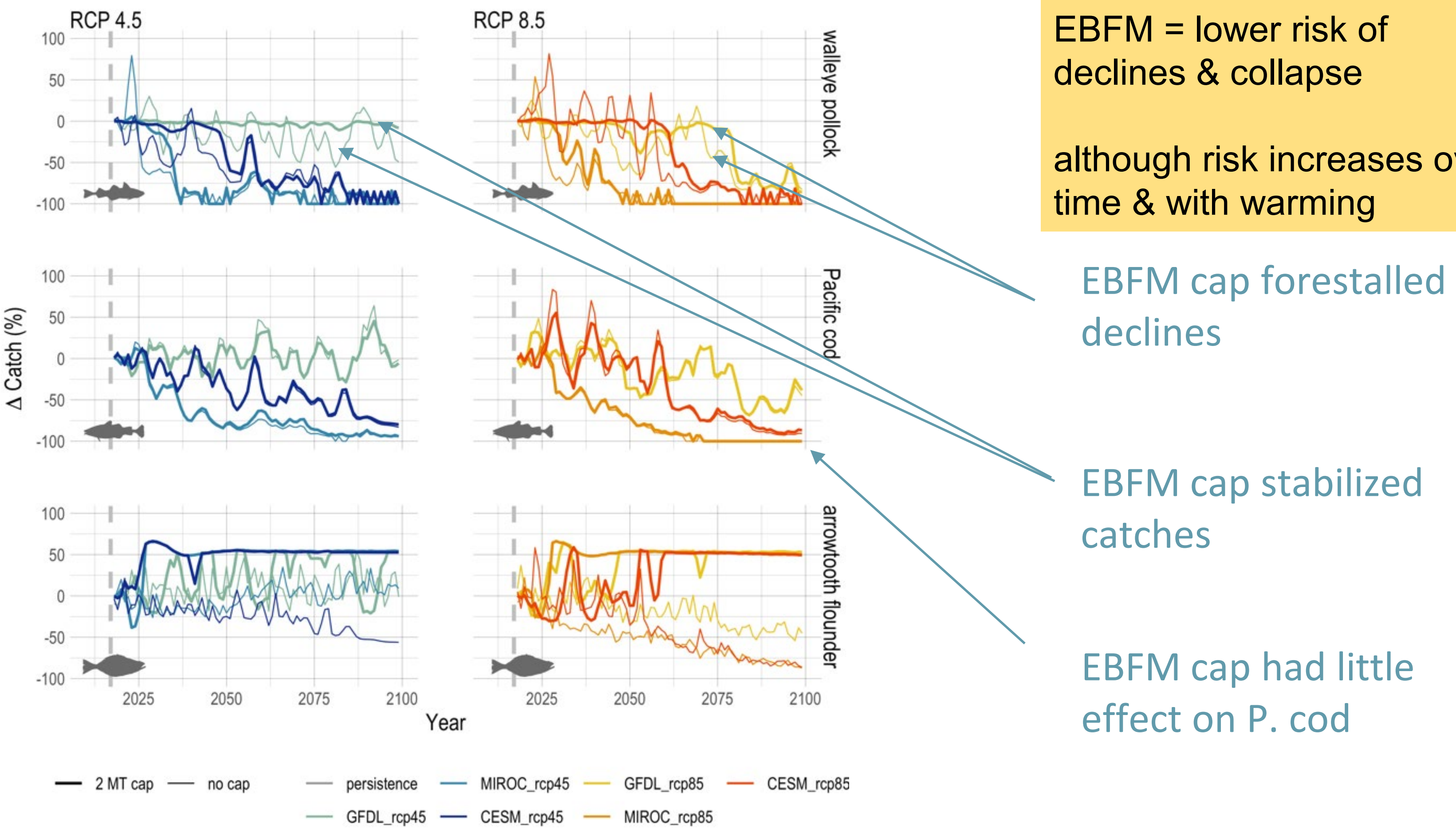


	Climate-effects on food-webs	Sloping HCR	Multispecies effects of 2 MT Cap
No fishing	X		
No-cap	X	X	
Status quo	X	X	X

ATTACH Model (Faig & Haynie 2020): http://doi.org/10.5281/zenodo.3966545

CEATTLE: EBFM vs non-EBFM cap

Assumes climate effects on recruitment, growth, & mortality



EBFM = lower risk of declines & collapse

although risk increases over time & with warming

Holsman, K.K., Haynie, A.C., Hollowed, A.B. et al. Ecosystem-based fisheries management forestalls climate-driven collapse. Nat Commun 11, 4579 (2020). https://doi.org/10.1038/s41467-020-18300-3

ACLIM1.0 – model limitations

- **Biological population-level (ABC) models were mostly SE Bering Sea only (standard BT survey grid) and non-spatial**

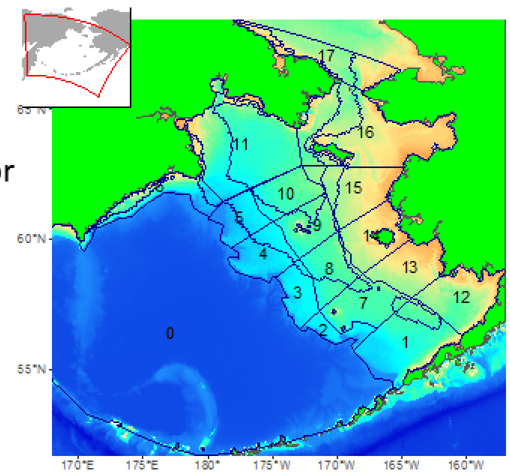
- **Benthic production (infaunal, epifaunal communities) low on data and dynamics are relatively poorly understood**

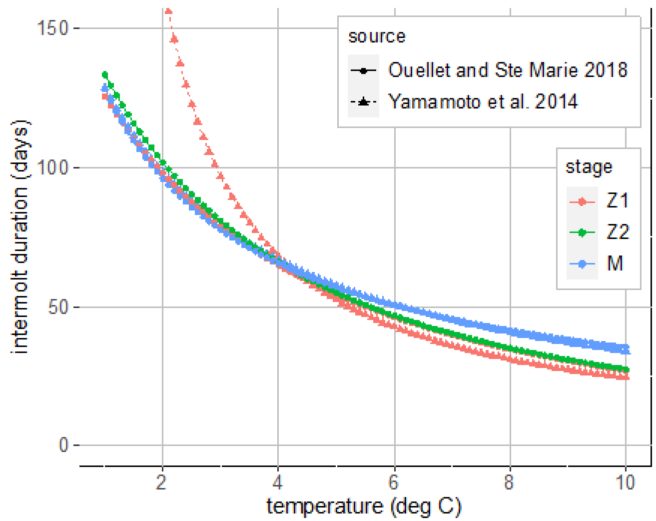
- **ACLIM 2.0 goals in next 6-12 months include model improvements in all of the above**

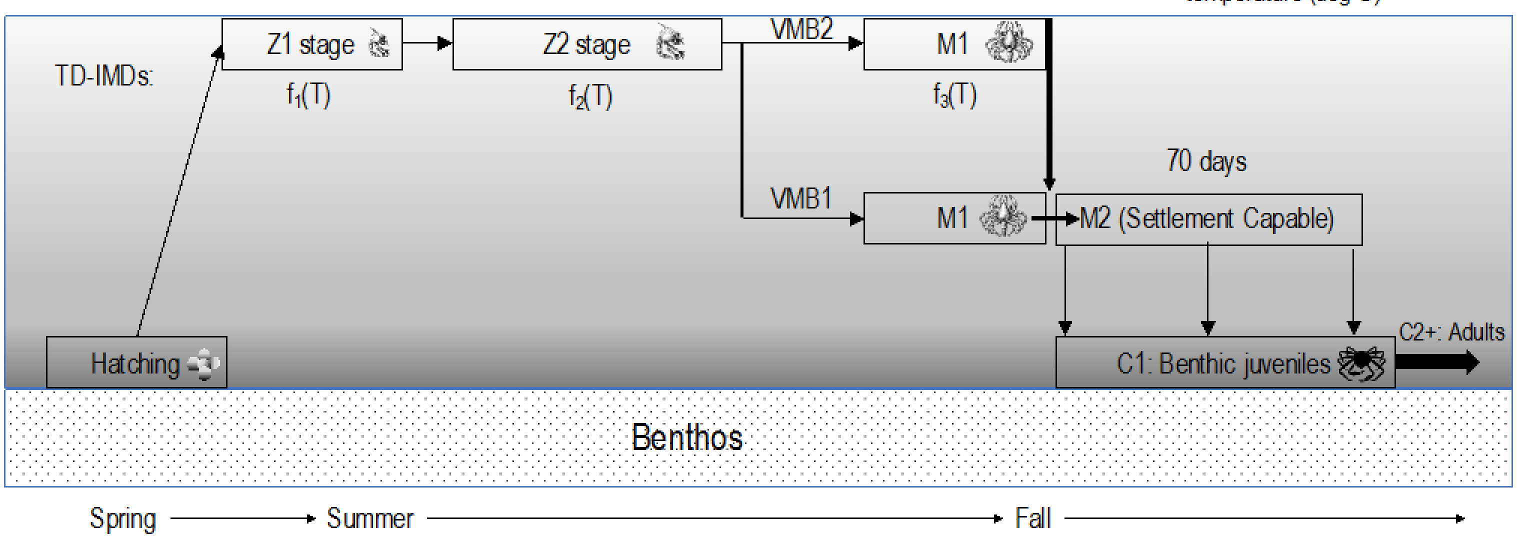
- **Some processes (e.g. predation) are emergent from models (e.g. through functional responses) however many processes (e.g. crab migration to deeper waters) need to be calibrated from past observations/analysis, spatial statistical models, etc. –** *we will get out what we put in*

Crab Individual-based model – Stockhausen et al.

- Temperature-dependent development rates
- Vertical migration behavior
- Larval mortality rates
- Settlement habitat characteristics
- Spatiotemporal hatch patterns

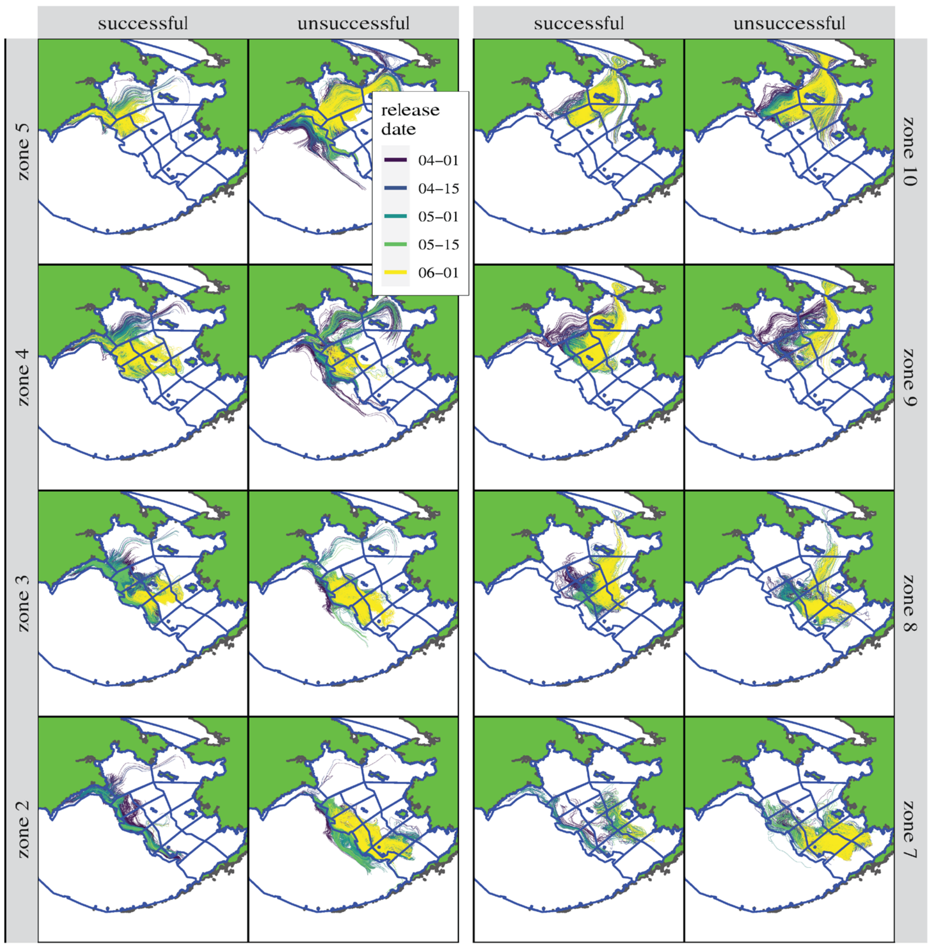




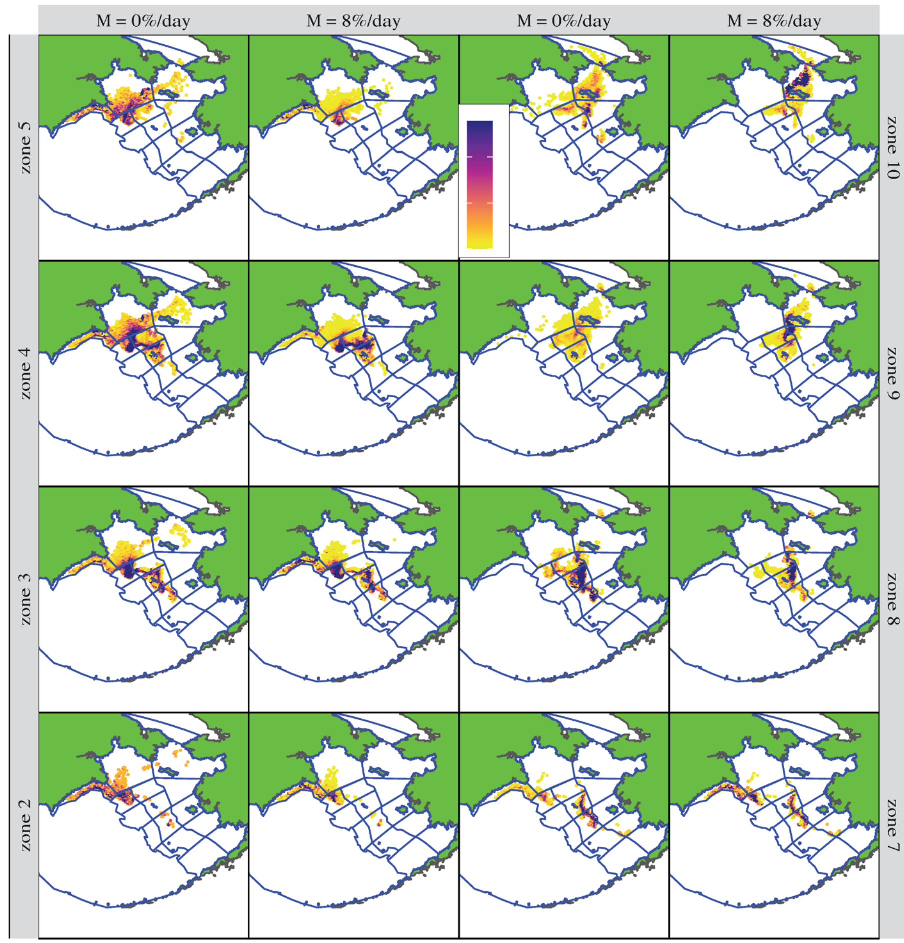


Crab Individual-based model – Stockhausen et al.

Dispersal Pathways

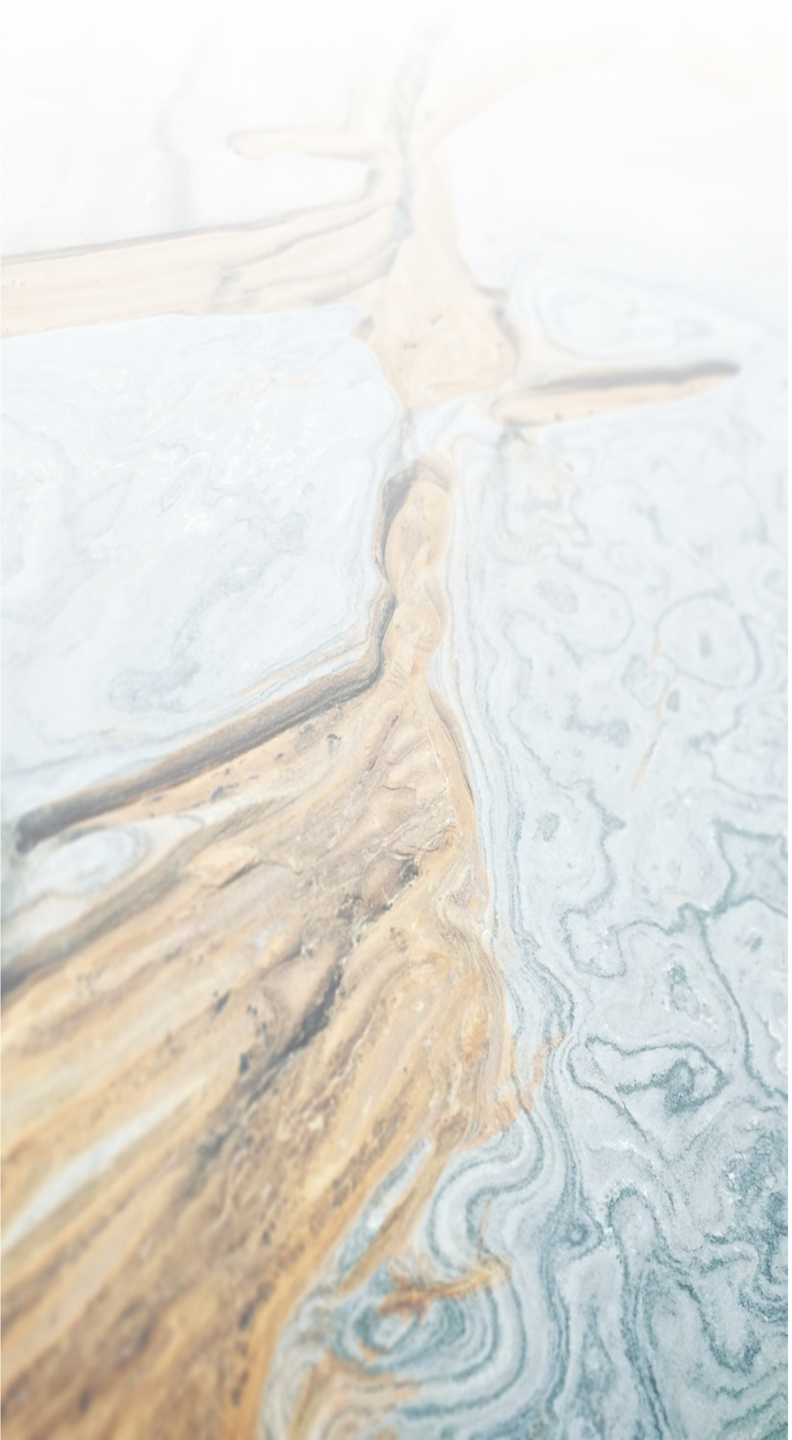


Settlement Patterns



Crab Individual-based model – Stockhausen et al.

- **Extend existing IBM (pelagic life stages) to early benthic instars**
- **Run model using regionally downscaled EBS ROMS model output based on CMIP6 projections**
- **Couple results to spatial assessment model as spatiotemporal early life connectivity patterns**



ACLIM 2.0 Next Directions

EBS social-ecological system climate risk analysis

Expanded management scenarios

Co-production of knowledge, community workshops, and social network modeling

Spatial distribution models & NEBS

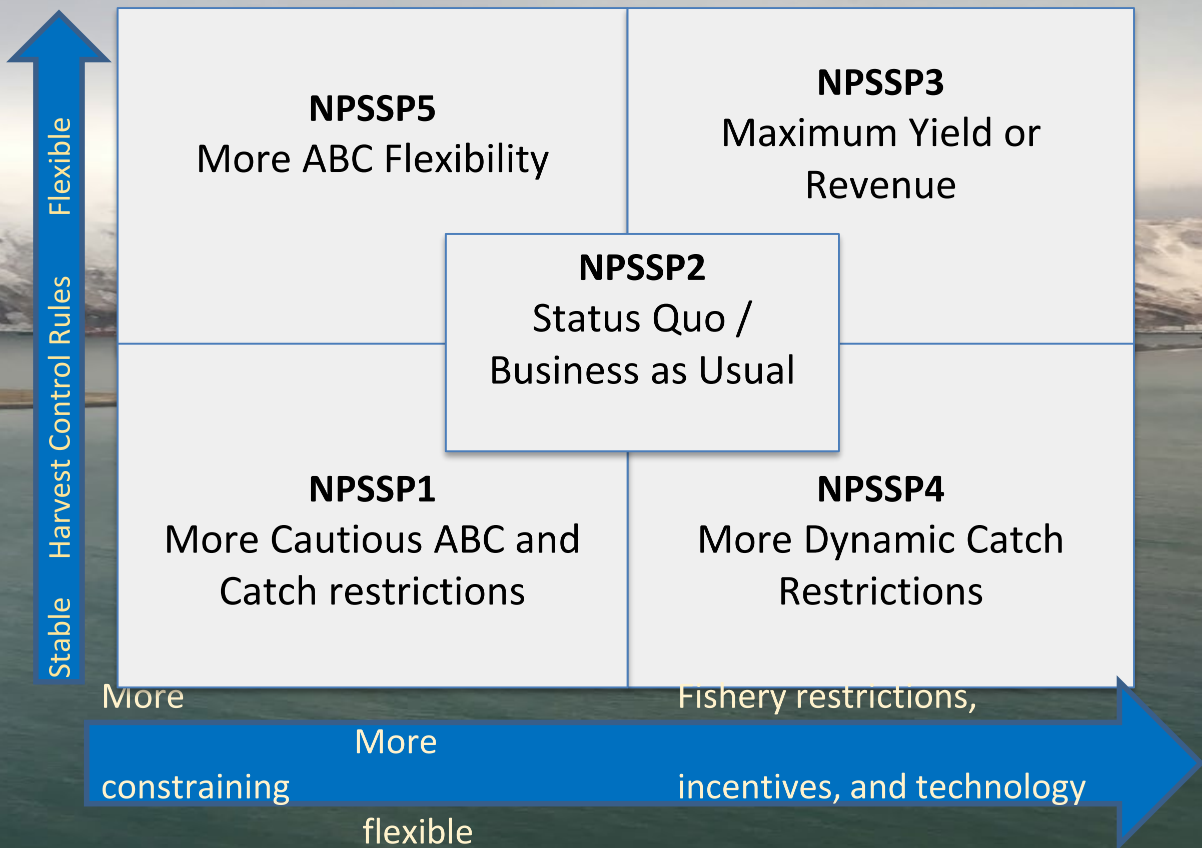
Expanded protected species analyses (marine mammals!)

Expanded **Ocean Acidification (OA)** and dissolved oxygen modeling

Expanded lower trophic and young of year modeling

GOA-CLIM: Gulf of Alaska **– Martin Dorn lead (Martin.Dorn@noaa.gov)**

ACLIM 2.0: General North Pacific Socio-Economic Pathways (NPSSPs)



<u>Other dimensions</u>

- Monitoring impacts
- Ecosystem models
- Emissions scenarios / models
- Diverse regulations

Note: there are additional complexities, too!

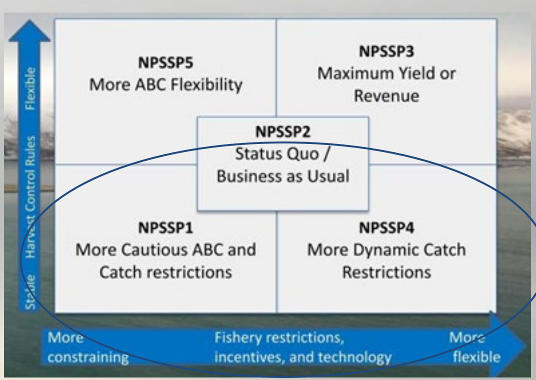
Different models use simulations that assess the impacts - ecological, economic, and allocational - of harvest control rules that impact ABC and regulations and economic drivers that impact catch of different species.

Caveats on Socioeconomic Scenarios

- Scenarios demonstrate trade-offs - there may be different trade-offs and priorities in the future.
- Some trade-offs may be shown beyond MSA rules - for example, understanding the impacts of loosening single-species annual catch limits in multi-species fisheries.
- Policy trade-offs examined - **these are not recommendations.**

Examples:

More <u>cautious / stable ABC</u> Measures

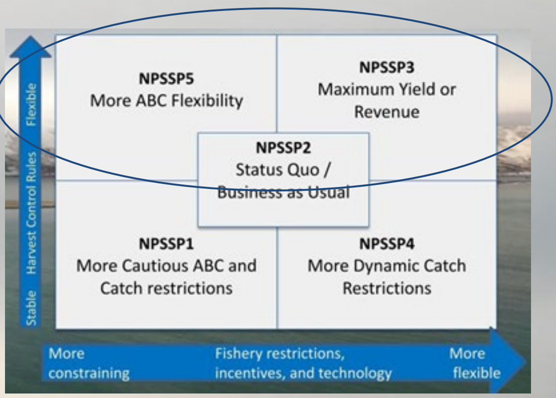


Strategy and Rationale of these measures:
Examine the impacts of scenarios that include more stable ABC policies to adjust ABC / Harvest Control Rules (HCR) with climate.

Example ABC / Harvest Control Rule (HCR) Features:

- Set harvest targets as a function of climate conditions (e.g., F50 % when temperature is high)
- Test regime-specific HCR slopes (warm-period HCR, vs. cold-period HCR).
- Include effects of climate on base functions in assessment (e.g., growth, recruitment, or mortality as a function of temperature or zooplankton)
- Account for species re-distribution in assessments (e.g., use climate-informed spatial distribution tools to adjust catch-ability).

Examples:



More <u>flexible ABC </u>Measures

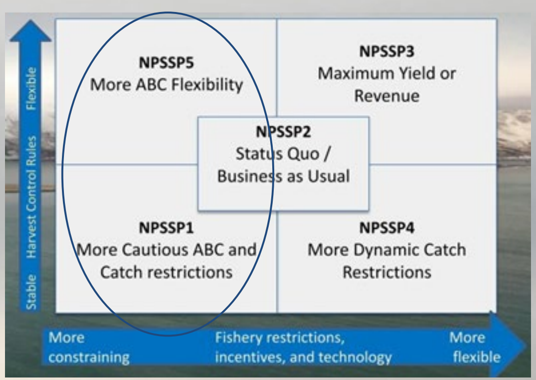
Strategy and Rationale of these measures:
Examine the impacts of scenarios that include more flexible ABC policies to adjust ABC / Harvest Control Rules (HCR) with climate and stock changes.

Example ABC / Harvest Control Rule (HCR) Features:

- **Allow multi-year ABCs.**
- **Evaluate minimum and maximum thresholds (e.g., B20 rule).**
- **Climate- or regime-specific B0 & B40.**
- **Utilize ecosystem and climate forecasts to increase overall sustainable catch and/or revenue.**
- **Explore measures that would increase stability of community access to resources.**

Examples:

More <u>restrictive</u> cap, catch restrictions, incentives, and technology



Strategy and Rationale of these measures:

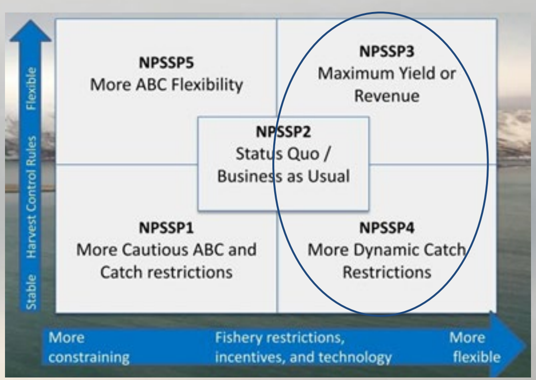
- Examine the impacts of scenarios that include measures that lower the cap or reduce the catch of different species.

Example Fishery Features:

- Impact of 1.6 MMT or climate-linked Ecosystem Cap / Optimum yield.
- Additional Spatial management related to protected species.
- Additional bycatch challenges that (further) limit harvest of some species.
- Increases in fishing costs or lack of growth in fish prices, leading to reduced incentives or ability to harvest as much of some species.

Examples:

More <u>flexible</u> cap, catch restrictions, incentives, and technology

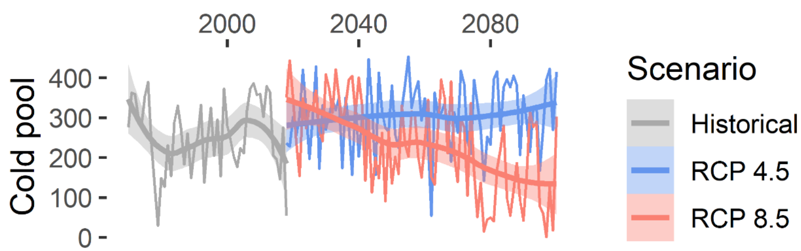


Strategy and Rationale of these measures:

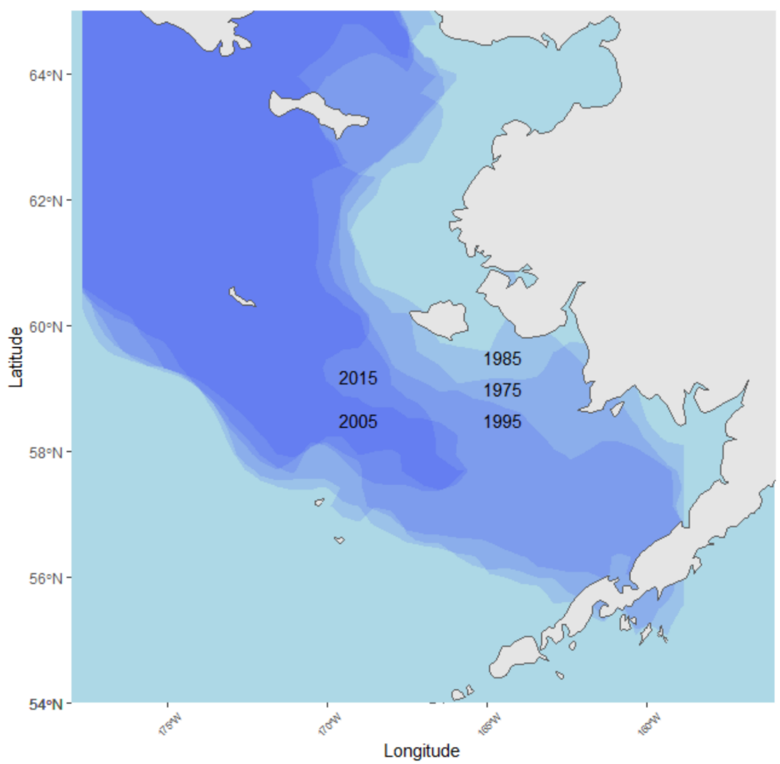
- Examine the impacts and trade-offs of scenarios that include factors that lead to more flexible catch restrictions and/or greater catch.

Example Fishery Features:

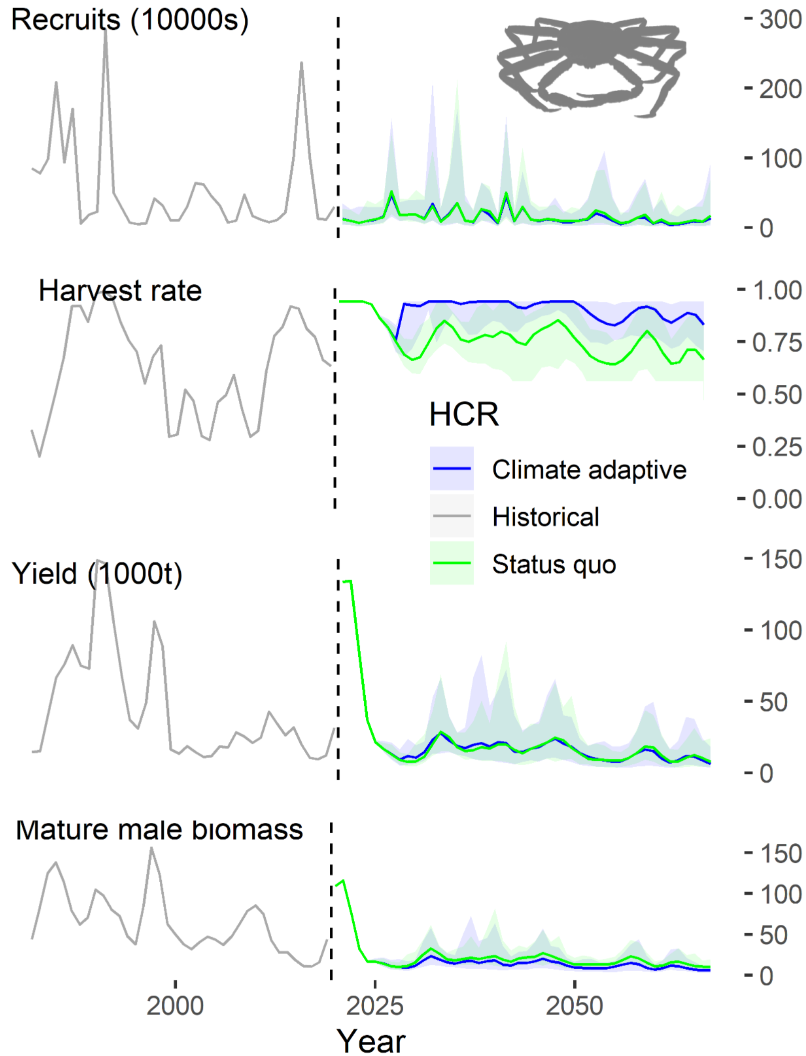
- Impact of 2.4 MMT (or other) Ecosystem Cap / Optimum Yield.
- Reduced spatial management measures when PSC quotas in place.
- Additional fishing flexibility in the Northern Bering Sea.
- Greater quota or bycatch flexibility (e.g., expanded Flatfish flexibility).
- Higher prices or improved fishing technology leading to greater catch.



Cold pool
2000
2040
2080
400
300
200
100
0
Scenario
Historical
RCP 4.5
RCP 8.5



64°N
62°N
60°N
58°N
56°N
54°N
Latitude
Longitude
2015
2005
1985
1975
1995



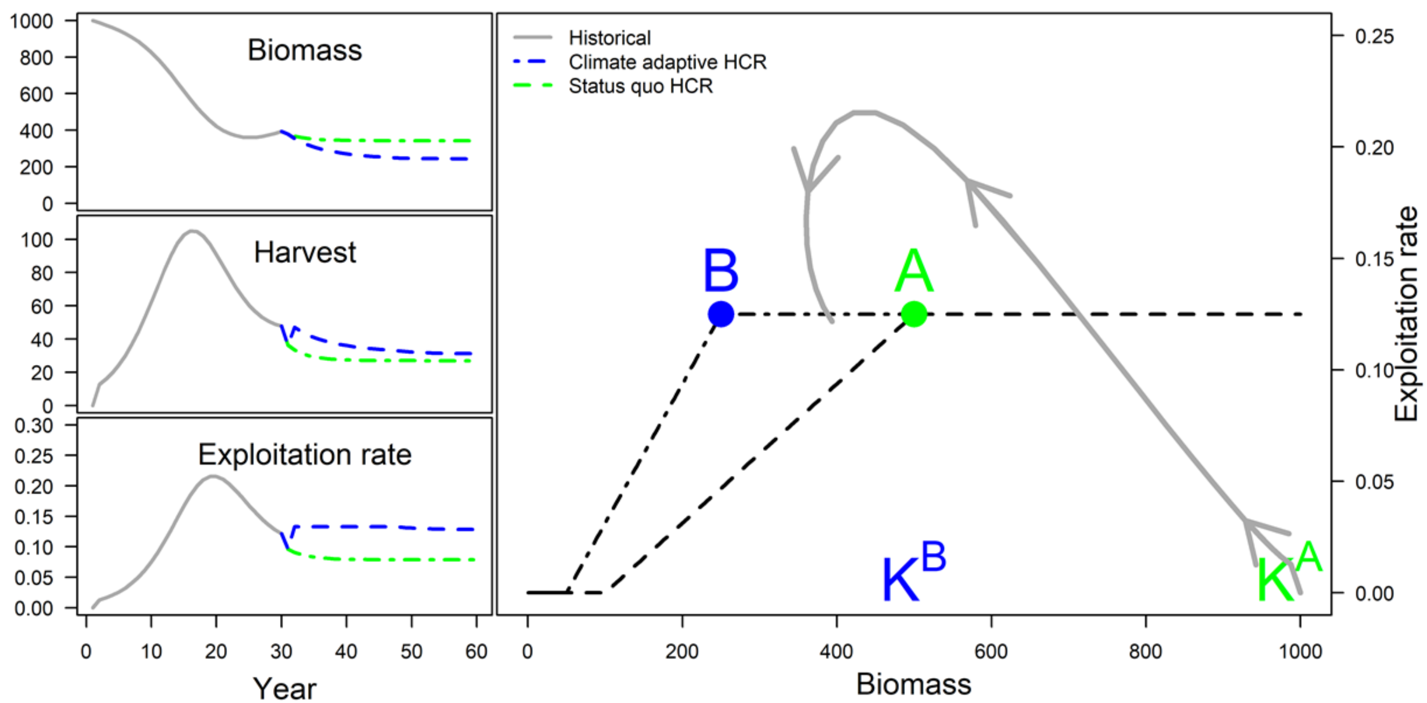
Recruits (10000s)
300
200
100
0
Harvest rate
1.00
0.75
0.50
0.25
0.00
HCR
Climate adaptive
Historical
Status quo
Yield (1000t)
150
100
50
0
Mature male biomass
150
100
50
0
2000
2025
2050
Year

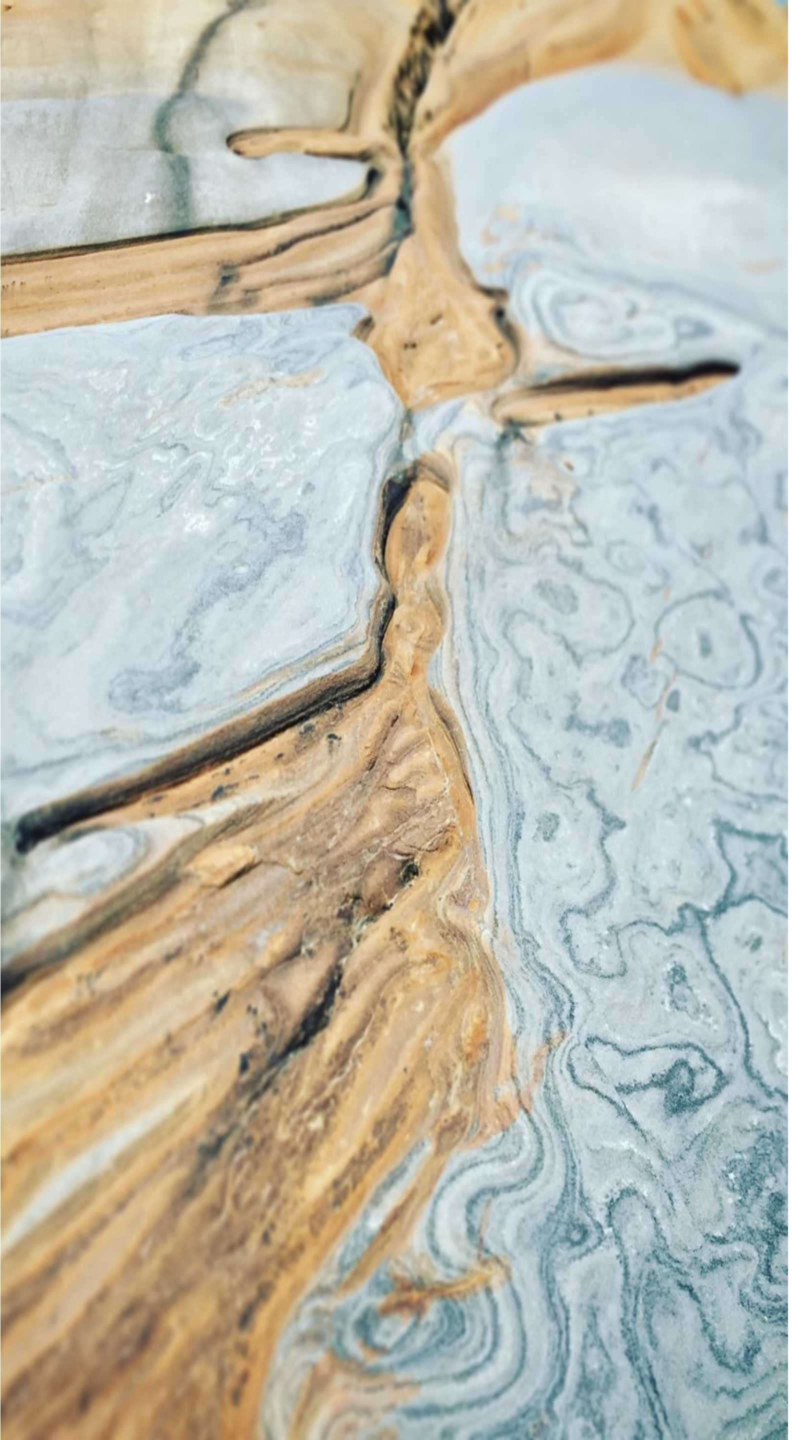
"Productivity paradox"

Climate adaptive harvest control rules can result in higher exploitation rates than the status quo control rule - long-noted in multispecies management contexts

Can arise when reference points adapt to a change in:

- Recruitment (when using a sloped harvest control rule; Szuwalski and Punt, 2013)
- Growth (Szuwalski et al., in prep)
- Natural mortality (Legault et al. 2016)
- Maturity





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  - Climate Regimes & Ecosystem Productivity (CREP)
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  - NOAA Integrated Ecosystem Assessment Program (IEA)
  - Alaska Fisheries Science Center

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